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Centre canadien de la technologie
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Centre canadien de la technologie des minéraux et de l'énergie

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Proceedings of
Eco-Indicators for Products and Materials
- State of Play '97:
An International Workshop

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Avant-propos

Les clients, le grand public et les gouvernements demandent que des critères environnementaux soient intégrés aux décisions touchant les produits et les matériaux. D'une part, de nouvelles méthodes d'évaluation des incidences environnementales sont disponibles et d'autres sont élaborées de façon continue. Ces méthodes d'évaluation sont développées afin d'aider les concepteurs industriels, les architectes, les agents d'approvisionnement, et les décideurs à faire des choix complexes sur le plan environnemental. Elles sont souvent basées sur les résultats d'études informatisées et élaborées d'après des techniques d'évaluation du cycle de vie. Les indicateurs des conditions écologiques sont des outils qui fournissent aux décideurs un seul nombre pour — évaluer les conditions écologiques— des matériaux, des procédés, des composants ou des produits. D'autre part, les modèles d'indicateurs des conditions écologiques manquent de transparence et donnent des résultats qui sont parfois trompeurs. Bien que plusieurs des méthodes courantes soient utilisées de bonne foi, les principes scientifiques sur lesquelles elles sont basées ne sont pas toujours clairs et les bases de données sont parfois incomplètes. Les producteurs et les manufacturiers souhaitent prendre des décisions judicieuses mais pour ce faire, ils ont besoin de modèles d'indicateurs des conditions écologiques conçus d'après des principes scientifiques et des données fiables. Le problème qui se pose est qu'en dépit d'un manque d'information et d'outils nouveaux mais non reconnus, les méthodes qui reposent sur les indicateurs des conditions écologiques sont nécessaires et continueront d'être utilisées

L'objectif de l'atelier étant de fournir un forum pour discuter de ces questions, il a réuni les principaux entrepreneurs et utilisateurs d'indicateurs des conditions écologiques en provenance de l'industrie, du gouvernement et de la communauté environnementale pour des délibérations portant sur les incidences environnementales, la science et les questions socio-économiques inhérentes aux indicateurs des conditions écologiques. L'atelier a été axé sur les méthodes basées sur les indicateurs des conditions écologiques destinées à être utilisées pour la conception de produits, la sélection de matériaux, en architecture et pour d'autres applications semblables

L'Association minière du Canada, l'Association canadienne du ciment Portland, le Conseil canadien du bois, l'Association canadienne de l'industrie du plastique et l'Association canadienne des producteurs d'acier ont coparainné l'atelier. Je remercie mes collègues qui ont rédigé des articles et qui ont servi en tant que président de session ou en tant que modérateur.

Alain Dubreuil

Foreword

Customers, the public and governments are demanding that environmental criteria be integrated into decisions about products and materials. On the one hand, new environmental scoring methods are available and continue to be developed. Such methods help with the complex environmental choices required by industrial designers, architects, procurement officers, policy-makers and other decision-makers. Methods are usually computer-based and built on life cycle assessment techniques. Eco-indicator tools often provide decision-makers with simple, single-number "environmental scores" on materials, processes, components or products. On the other hand, eco-indicator models are not very transparent and they generate results that can be misrepresentative. While many of the current methods are well intended, the scientific basis for their formulation is not always clear and their data bases are sometimes incomplete. Producers and manufacturers want to make sound decisions but, to do so, they need eco-indicator models based on better science and higher quality data. The emerging dilemma is that, despite insufficient information and novel yet unproved tools, eco-indicator methods are needed and will continue to be used. The objective of this workshop was to provide a forum for the discussion of these issues.

The event brought together leading developers and users of eco-indicators with industry, government and the environmental community to discuss environmental, scientific, social and economic issues related to eco-indicators. The workshop focused on eco-indicator methods for product design, architecture, materials selection and similar applications.

The Mining Association of Canada, the Canadian Portland Cement Association, the Canadian Wood Council, the Canadian Plastics Industry Association, and the Canadian Steel Producers Association sponsored the worshop. Thanks are expressed to my colleagues who contributed manuscripts and served as session chairs or moderator.

Alain Dubreuil

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Résumé

Jean-Claude St-Pierre
Introductory Remarks

La prise de décisions environnementales devient un élément de plus en plus important de notre façon de faire des affaires. Toutefois, analyser une grande quantité de données pour aboutir à une décision judicieuse peut s'avérer une lourde tâche et des méthodes d'évaluation simplifiées seraient préférables. Il n'en demeure pas moins qu'indubitablement, des décisions sont prises et que les mauvaises décisions, s'il en est, affectent tous les Canadiens. Par conséquent, il est important que nous ne surestimions pas les risques environnementaux au point de nuire indûment au secteur des ressources naturelles. La Politique des minéraux et des métaux du gouvernement du Canada se fonde sur la bonne gestion des matériaux en fonction du développement durable. Ce principe qui découle des principes de gestion du cycle de vie des matériaux met en lumière les risques liés aux métaux et vise à les contrer. En définitive, dans notre démarche d'évaluation, il est primordial d'éviter les décisions impulsives et de rester ouverts à toutes les idées et suggestions de ceux qui oeuvrent dans le domaine de la prise de décisions environnementales.

Gil Friend
Key Note Lecture
Eco-indicators: What kind? What for?

Le but principal d'un indicateur est d'indiquer les orientations avantageuses sur les plans environnemental, économique, stratégique et social. Il existe différents types d'indicateurs tel les dépenses sur le plan environnemental, la quantité de rejets toxiques, la production, l'analyse du cycle de vie, les indicateurs de développement durable...
Les qualités d'un bon système d'indicateurs sont les suivantes : il intègre la dimension affaires et la dimension environnementale de l'entreprise; il fait partie du système de gestion de l'entreprise. Le nombre des indicateurs est limité mais ces derniers en incorporent plusieurs autres et indiquent la voie à suivre.
De la même façon, le gouvernement doit résister à la tentation de gérer la complexité en suggérant un trop grand nombre d'indicateurs. Le traitement des données environnementales et commerciales afin de produire de l'information utile pour les décideurs de l'entreprise constitue un autre défi.
En résumé, l'objectif doit être stratégique plutôt que quantitatif. La question qui se pose est la suivante : « Comment pouvons-nous réaliser à la fois nos objectifs environnementaux et financiers? »

Mark Goedkoop
The Eco-indicator 97 Explained

L'article présente une description du modèle Eco-indicator 97. Le modèle permet à des designers de produits qui ne sont pas des experts dans le domaine environnemental de faire

des choix qui tiennent comptent de l'ensemble du cycle de vie. Le modèle comprend un système de pondération qui permet de consolider toutes les données d'inventaire en un seul indice. De plus le designer a accès à une base de données contenant les indices environnementaux de plusieurs matériaux et procédés.
Le modèle comprend deux parties. La première partie utilise l'information scientifique disponible la plus pertinente afin de calculer les dommages écologiques moyens d'une émission. Le choix des valeurs de société qui permettent la pondération des impacts entre eux est inclus dans la seconde partie.
Le modèle inclut l'utilisation de ressources non renouvelables, l'utilisation du sol et les aspects du devenir du produit (dispersion et dégradation) et de l'exposition à celui-ci « *fate analysis* ». À l'heure actuelle le modèle Eco-indicator 97 n'est théoriquement valable que pour l'Europe.

Yasunari Matsumo, Atsuhi Inaba, Norihiro Itsubo et Ryoichi Yamamoto
Development of Life Cycle Impact Assessment Weighting Methodology for Japan - Weighting Method Based on Distance-to-Target Principles -

Bien que plusieurs analyses de cycle de vie aient été faites au Japon les évaluations des impacts ont été plutôt rares. Cet exposé présente une méthode de pondération basée sur le principe de la distance à la cible « *distance-to-target* » spécifique aux conditions environnementales japonaises.
La méthodologie est fondée sur les principes formulés par SETAC Europe. Les facteurs de pondération pour les impacts globaux sont calculés à partir des objectifs fixés par le gouvernement japonais. Les facteurs de pondération pour les émissions qui ont des impacts locaux ont été définis à l'échelle de la préfecture à partir de la situation environnementale locale. Ainsi lorsque la moyenne annuelle de la concentration d'un polluant est inférieure aux standards, le facteur de pondération est nul.
À titre d'exemple, le calcul de l'éco-indicateur a été effectué en utilisant le même inventaire à trois locations géographiques différentes afin de montrer la dépendance entre les conditions locales et l'impact environnemental.

W.B. Trusty et J.K. Meil
Athena™: An LCA Decision Support Tool for the Building Community

Les auteurs présentent une revue du projet et du modèle Athena^{MD}, y compris les résultats de l'application du modèle à un édifice générique. L'article souligne plusieurs points liés à l'application du modèle à des immeubles et à l'interprétation des résultats tels que l'équivalence fonctionnelle, l'établissement d'un cadre décisionnel approprié et l'évaluation de la portée. Le modèle Athena^{MD} aide les concepteurs à mieux définir l'impact environnemental en indiquant de manière parallèle les effets de plusieurs schémas théoriques. Les associés de recherche d'Athena^{MD} ont maintenant :

- complété l'analyse partielle de l'inventaire du cycle de vie de la charpente depuis l'extraction de la ressource naturelle jusqu'à la production de la structure d'acier, du

bois, et du parpaing, ainsi que de plusieurs matériaux de recouvrement et du placoplâtre;
- élaboré une mesure de l'impact écologique de l'extraction des ressources; et
- entrepris une étude de cas portant sur l'énergie requise pour démolir un édifice.

Des études portant sur d'autres types de revêtement, des matériaux isolants, les portes et fenêtres, les peintures et teintures et autres matériaux utilisés pour la toiture sont prévues ou en cours.

Martin Baitz, Konrad Saur et Johannes Kreißig
Life-cycle-engineering: Requirements and Limitations of Indicator and DFE-tools

L'analyse du cycle de vie est une méthode qui permet de générer de l'information fiable et sûre concernant des systèmes complexes. L'approche cycle de vie-application technique permet de coupler les données obtenues par l'analyse du cycle de vie avec les aspects sociaux-économiques. Cette approche doit être développée en un outil « *DFE Tool* » qui permettra au designer d'identifier des situations critiques lors du choix de matériaux. Cet outil doit tenir compte de la situation particulière des différents secteurs (source d'énergie, efficacité énergétique, marché, région ...) afin d'obtenir un profil écologique suffisamment précis des produits. La transparence et la flexibilité du modèle sont de toute évidence des paramètres importants. Afin de décrire la pertinence écologique du choix des produits, l'hypothèse de l'impact potentiel a été retenu, c'est-à-dire le pire des impacts. Les facteurs de pondération peuvent être changés par l'usager afin de refléter la vision de l'entreprise et les conditions nationales

Stanley Rhodes et Linda Brown
A Technical Framework for Life-cycle Impact Assessment and its Potential Application in Measuring the Degree of Sustainability of Industrial Systems

Le concept de développement durable inclut les dimensions environnementales et le développement économique. Les intervenants ont essayé de développer des stratégies « durables » mais l'un des obstacles est le manque d'outils permettant de mesurer de façon objective la « durabilité ». L'analyse du cycle de vie de par sa perspective globale est une pierre angulaire qui doit être utilisee afin d'élaborer un système qui nous permette de mesurer le niveau de durabilité des systemes industriels.
L'article décrit le contexte historique de l'élaboration de l'analyse du cycle de vie ainsi que le lien ténu entre les émissions et les impacts environnementaux. Les auteurs proposent le modèle LCSEA « *Life-cycle stressor-effect assessment* » qui permet de calculer une valeur d'indicateur d'impact significative pour le système étudié. De plus, le modèle permet de calculer des seuils « *threshold* » en dessous desquels aucun impact environnemental n'est observé ce qui permet de simplifier l'analyse du problème. Comme le modèle LCSEA représente le lien entre le système et ses incidences, non seulement les quantités de matière émises sont elles importantes mais la dimension temporelle l'est également. Le système agent stressant - impact peut être caractérisé selon des paramètres spatiaux, temporels, dose-réponse et seuil.

Duncan Noble
Eco Indicators, Customer Value and Environmental Leadership

Les éco-indicateurs nous invitent, entre autres, à nous poser de bonnes questions qui nous sensibilisent davantage. Ils sont utilisés comme instruments de mesure et permettent de faciliter la mise en oeuvre du plan stratégique qui répond aux fluctuations du marché. Les éco-indicateurs nous facilitent une communication avec nos clients, nos fournisseurs, nos actionnaires, nos employés et la communauté.
La stratégie environnementale a évolué depuis 25 ans. Elle est passée du traitement des effluents à la prévention de la pollution, à la bonne gestion des produits « *product stewardship* » et au développement durable. Les incidences sur les opérations financières se sont traduites par une augmentation des coûts de production suivie d'une augmentation des revenus. Selon la politique environnementale de Nortel, la performance de nos opérations doit excéder la performance exigée par les normes environnementales; nous respectons les valeurs de nos clients et nous mettons en commun nos connaissances sur l'environnement.
Divers exemples du design au service de l'environnement « *Design for Environment* » sont donnés : nouveau type de soudure, nouveau concept de téléphone, utilisation des câbles d'alimentation électrique pour transmettre l'information. Le fait d'inclure la dimension environnementale à l'étape du design permet de faciliter le recyclage, d'optimiser la réutilisation de certaines composantes du produit, d'augmenter l'efficacité énergétique et d'optimiser la disposition finale quelle qu'elle soit.

Agneta Wendel
EPS a Tool to Make LCAs within Product Development Processes

Chez Volvo, la stratégie est de déléguer, dans la mesure du possible, les décisions environnementales aux ingénieurs responsables du design. L'outil informatique utilisé est le EPS « *Environmental Priority Strategies* » qui utilise le concept de l'analyse du cycle de vie. Le logiciel EPS est conforme aux exigences de la norme ISO 14040 et possède un système de pondération fixe. Les impacts environnementaux sont calculés en ELU « *Environmental Loading Index* ».
Les objectifs sont de maintenir la diversité biologique, la santé humaine, la production biologique, les ressources naturelles et les valeurs esthétiques.

Nils K. Larsson et Raymond J. Cole
A Second-Generation Environmental Performance Assessment System for Buildings

Nous vivons à une époque où l'on demande des produits et des services de qualité. Qu'en est-il de la certification environnementale des édifices? À l'exception de certains hôtels et restaurants où les critères de performance sont basés en grande partie sur le service, il n'y a pas de système de normalisation environnementale pour les bâtiments qui soit reconnu universellement.

Le *Défi des Bâtiments Écologiques 1998 - Green Building Challenge '98* est un projet international auquel participent quatorze pays. Les participants à ce projet visent, d'une part, à vérifier et à démontrer des méthodes nouvelles pour mesurer la performance environnementale des édifices et, d'autre part, à diffuser les résultats.
Il y a plusieurs systèmes dits de première génération qui permettent d'établir la performance environnementale des édifices et les auteurs font un examen rapide de trois systèmes. Ces systèmes sont cependant difficilement applicables sur une vaste échelle pour diverses raisons.
Le *Défi des Bâtiments Écologiques 1998* propose de façon originale une méthodologie qui tient compte des particularités régionales et qui offre à l'architecte des suggestions quant aux améliorations et à la conception. Les concepteurs du modèle ont réalisé que la plus grande partie des impacts d'un bâtiment découle de son usage. Le logiciel informatique ne contient donc pas les impacts environnementaux des matériaux de construction. La version actuelle décrit la performance *potentielle* d'un bâtiment par opposition à la performance *actuelle*. En effet, la performance actuelle dépend du comportement de ses utilisateurs, ce qui peut présenter des difficultés sur le plan de la modélisation. De plus, les versions subséquentes du logiciel pourront incorporer d'autres modèles spécialisés tel Athena[MD].

Jane C. Bare
Environmental Assessment and Eco-indicators in the U.S. EPA

Les programmes récents de prévention de la pollution, d'analyse du cycle de vie et de développement durable requièrent une analyse de l'impact environnemental afin d'appuyer la prise de décision. Les analyses d'impacts environnementaux traditionnels se résumeraient en une simulation haut de gamme d'une seule catégorie d'impacts sur un seul media. L'analyse de plusieurs types d'impacts requiert l'utilisation de techniques moins sophistiquées tel les éco-indicateurs. Les simulations présentement utilisées sont-elles suffisamment précises pour constituer un outil de décision?
L'article décrit plusieurs programmes et projets de l'*Environmental Protection Agency (EPA)* qui tentent de caractériser des impacts environnementaux afin de pouvoir prendre de bonnes décisions sur le plan écologique.
En conclusion, les éco-indicateurs n'en sont qu'à leurs premiers balbutiements et il reste beaucoup à faire pour les améliorer.

Marlo Raynolds
Environmental Performance Indicators - an ENGO Perspective

Les indicateurs de performance environnementale sont utilisés par l'industrie pour mesurer et suivre la performance sur le plan écologique et pour communiquer les résultats aux gestionnaires, aux législateurs, aux groupes environnementaux, au public ainsi qu'à leurs clients. À l'interne, ces indicateurs de performance environnementale ont été les catalyseurs pour l'amélioration de la performance.
Le message qui doit être transmis aux groupes environnementaux étant le niveau de la performance environnementale ne peut être véhiculé par un seul nombre. En effet trop

d'information est perdue dans le processus d'intégration. Pour être efficients, les indicateurs de performance environnementale doivent communiquer les données les plus pertinentes et les plus représentatives en fonction de la performance environnementale. Le premier type d'indicateur fournit une mesure de la quantité absolue de ressources qu'une entreprise utilise de même que de la quantité de rejets qui sont produits. Le second type d'indicateur établit un ratio entre, d'une part, les ressources utilisées et les déchets produits et, d'autre part, les biens ou services produits. Les carburants automobiles sont donnés en exemple pour l'application de ces indicateurs.

Alain Dubreuil
Analysis of the Eco-indicator 95 Model

Les designers de produits n'ont pas nécessairement les connaissances environnementales qui leur permettent de faire des choix de matériaux qui tiennent compte de l'environnement. Le modèle Eco-indicateur 95 leur permet de « simplifier » l'interprétation des résultats de l'analyse du cycle de vie.
L'article comprend une évaluation préliminaire de certaines parties du modèle tel que la méthodologie, les bases de données et les résultats obtenus au moyen du modèle. Les deux documents consultés sont : *The Eco-indicator 95, Final Report* and *The Eco-indicator 95, Manual for Designers* qui sont disponibles auprès de PRé Consultants. Trois logiciels ont de plus été consultés : *Eco-it*, *Simapro* et *IDEMAT*. Les deux premiers sont produits par PRé Consultants tandis que le dernier est publié par l'Université Delft, en Hollande.

Certains designers utilisent des modèles basés sur des éco-indicateurs pour améliorer leurs produits et *Eco-it* ainsi qu'*IDEMAT* sont des outils populaires Pour prendre de meilleures décisions environnementales, ces points méritent d'être considérés

- améliorer l'équation de base afin de mieux saisir l'évolution des émissions en fonction du temps;
- considérer l'introduction de la notion d'utilisation sûre ;
- perfectionner la connaissance de la recyclabilité des produits métalliques ,
- améliorer la modélisation des données ,
- considérer la situation environnementale locale à l'extérieur de l'Europe , et
- éviter de porter des jugements de valeur qui ne sont pas basés sur le modèle.

Table ronde

Une table ronde animée par Patricia Hayes et constituée de George Venta, Matthew Goldman, Vic Shantora, Thomas Gameson, Steven Young, Hal Levin et Ron Harper a étudié trois questions clés.
1. Quels sont les éléments essentiels d'un bon modèle?
Un bon modèle doit comporter une analyse de la propagation des incertitudes dans les résultats et les conclusions. Le modèle doit être transparent. Certaines mesures d'impact sont nécessaires afin de mettre l'indicateur en contexte.

2. Quels sont les usages d'un modèle?
Dans les grandes entreprises, les modèles d'éco-indicateurs servent à optimiser des designs et, en conjonction avec un système de gestion environnemental, à améliorer la performance environnementale. Il servent à communiquer avec les clients et le public. En Europe, la performance environnementale d'une entreprise peut être évaluée au moyen d'un modèle semblable à l'Eco-indicator 95 ce qui peut donner lieu à certaines subventions de l'État.

3. Quels sont les obstacles et les possibilités liés à l'usage de tels modèles?
Obstacles :

- insuffisance de données
- méthode de comparaison des différents types d'impacts
- paralysie par l'analyse
- besoin de standardisation et de révision par des pairs
- crainte de la part de l'industrie de la perte de confidentialité

Possibilités :

- faire les choses correctement
- utiliser à l'interne un modèle plus rapidement. En effet si le modèle ne sert pas d'outil de communication avec l'environnement externe (groupes d'intérêt, clients ...), sa mise en oeuvre peut être plus rapide car elle n'exige pas une revue des résultats par des pairs.
- utiliser pour les études d'impact les documents de la série ISO 14040
- mettre en commun les bases de données tel que le *Canadian Raw Materials Data Base*
- faire converger les intérêts des universitaires, de l'industrie, des consultants et des gouvernements
- devenir un important outil de décision

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Welcome and Keynote Address

INTRODUCTORY REMARKS
by
Jean-Claude St-Pierre
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I would like to welcome each one of you to this international workshop. It is good to see so many of you who are interested in the challenging topic of eco-indicators. It is also very gratifying to see all the different natural resource sectors represented here.

Environmental decision-making is becoming a critical part of the way we do business. Canadians want their governments and the business community to make good choices when it comes to the environment.

Environmental decision-making is often highly complex and requires a great deal of recent and relevant technical data. Certain types of tools, such as life-cycle analysis, look at ways to examine all aspects of material production, use, potential re-use, and disposal. More and more companies are applying this type of evaluation with greater and greater frequency.

Short cuts are often desirable. If there are ways to yield critical information that lead to the right choices without exhaustive and lengthy analysis, they will be used. It is important to acknowledge that it is not possible to stop making decisions in the absence of full scientific certainty of information.

How do we then best serve the Canadian public in their search for sound environmental decision-making?

One way to start is to examine what are the benefits and limitations of environmental decision-making tools such as eco-indicators. When do they work, where do they need improvement, who needs them and why and what is their role in protecting the environment.

Inappropriate decisions affect all Canadians. It is vitally important that we address environmental issues appropriately but it is equally important not to overestimate environmental risk to the degree that it inappropriately affects our natural resource sectors.

My department, Natural Resources Canada, has produced a Minerals and Metals Policy for the Government of Canada and in this policy we outline many of the important considerations in promoting sustainable development in the minerals and metals industry.

One key consideration is what we call the safe use principle for minerals and metals. This concept is an extension of life-cycle management principles and is aimed at understanding the risks posed by metals, setting out reasonable and realistic courses of action. In other words, let us put our time and effort to solving real issues.

I mention this today because all of you are involved in developing tools that help individuals in many different walks of life make those kinds of decisions. The message I want to stress is: "let's not make hasty judgements, let's be open and transparent in our approaches, let's accept that science and our thinking are evolving on these issues and let's try to open the debate up to all the people involved in environmental decision-making."

I would encourage all of you to speak up and share your experiences and priorities. By doing so we can start working on the tools that will satisfy the needs of many users.

Identify the best times and places to use tools of the eco-indicator type and perhaps also offer some guidance on when they are best left unused.

This type of analysis we are discussing today requires an interpretation across sciences and professions.

I wish you all the very best during your deliberations today, I am certain it will be a productive and meaningful exchange.

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  - **Nutrient cycle - SCA's carbon management**
  - **Technical cycles - Braungart**
  - **TakeBack Economic cycle - Electrolux EOL value**
- **Ecosystem Indicators**
  - **"Ecological Balance Sheet" - soils and water protection, biodiversity, yields and profitability (AssiDomän)**
  - **Ecological Footprint / Rucksack (Rees and Wackernagel; Wuppertal)**
- **Socio-Ecological Indicators**
  - **Biospheric loading - sinks, not sources**
  - **Thermodynamics + "balance of flows" (Holmberg)**

Eco-Indicators for Products and Materials • Natural Resources Canada • November 1997
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Practical considerations: Reality based management

- Laws of nature: The physics that underlies the chemistry that underlies the biology that underlies the ecology that underlies the human economy.
- Naked economic truth: Every business produces two things
- Challenge: WBARI

Practical considerations: Strategy+Management+Policy

- Strategy: Central business proposition
- Management: Integration
- Policy: Leverage, timeliness, certainty, market-based

Practical considerations: Procurement

- Vectors
- Thresholds
- Qualitative & Quantitative Tools - Checklists, Questionaires, LCA, Tracking/Feedback/TQM

Challenge: Turn Data into Information

- Trends
- Ratios
  - Resource productivity & waste intensity
  - Conversion efficiency (yield)
  - Throughput efficiency - P/(P+NPO)
  - Content
- Benchmarking - over time; within enterprise, between units; against industry
- Align with economic measures

Which to use? How to choose?
(Ayres)

- Navigation
- Suite vs single
- Efficiency, benchmark
- Salient (business linkage)
- Scalable (company, multicompany, region, nation)
- Avoid suboptimization

Which to use?
How to choose?
(*Company Environmental Reporting* - UNEP)

- Comparability
- Scope
- Credibility
- Quantification
- Transparency
- Extendability

Which to use?
How to choose?
(Adriaanse/NEPP)

- Requirements:
  - Limited number, as aggregative as possible
  - Definite appeal, aptly presented
  - Reflect a trend, with appropriate time scale
  - Relate to cause and effect
  - Relate actual developments, in time, to objectives and actions
  - Verifiable and reproducible

Which to use?
How to choose?
(Adriaanse/NEPP)

- "Key points" for development of indicators
  - Quality aspects
  - Sensitivity in time
  - Policy relevance
  - Recognizability and clarity
- "Governing criteria" for effective metrics
  - Data available and accurate
  - Metrics are meaningful and actionable

Self-Control
(Juran)

- To be in a state of self-control, a person must know:
- what he or she is supposed to do
- what he [or she] is actually doing
- what choices he has to improve results wherever necessary
- "If any of these three conditions are not met, a person cannot be held responsible."

In Closing

- Goal? Strategic rather than quantitative
- No longer a question of "Can we afford quality?"
- Now: "How can we profitably accomplish both environmental and financial goals?"
- Factor 4? or 10? or ?

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Session 1: Developers of Eco-indicator Models

PRé

product ecology consultants

The Eco-indicator 97 explained

Working document

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1. Introduction

This paper gives an overview of the Eco-indicator 97 methodology that is currently being developed by a group of LCA and environmental experts, under commission of the Dutch Ministry for Environment. (VROM). It is intended to provide an overview of the core concepts.
The Eco-indicator methodology is presently being developed for Europe, but it is quite straight forward to adapt the method to the circumstances in different parts of the world.

Designers are not environmental specialists and they never will be. Still designers make many decisions that influence the properties of products and thus the environmental load that will occur during the product lifecycle. We cannot expect that they will consult an environmental expert in every case, and therefore they need a simple, yet reliable tool to measure the environmental consequences of their design decisions.

Lifecycle assessment has been developed to be such a tool, but so far the practical use of LCA in design projects is hampered by two major obstacles:

1. The results of an LCA are often hard to interpret, as they usually contain data on numerous environmental flows.
2. The execution of an LCA takes to much time to be useful to designers.

The Eco-indicator methodology solves these problems in two ways:
A weighting methodology transforms the LCA results into a single score.

1. The methodology is used to calculate standard indicator values for a large number of frequently used materials and processes. These figures are available to designers off the shelf.

In the Eco-indicator 95 project we have calculated and published over 100 such scores. Companies such as Philips have calculated several hundred of additional scores for specific materials, such as electronics and batteries. With these scores designers are able to analyse their design in just a few minutes.

2. The core concept of weighting

The Eco-indicator score should somehow represent the perceived seriousness of an environmental load of a product. Perceived seriousness is subjective by definition, as the seriousness of something is very much dependent on values. A simple example can illustrate this:

Suppose we can calculate that during the lifecycle of product A, a number of toxic emissions are released that will have significant impact on human health, while product B will cause significant acidification that will damage ecosystems. A nature lover may prefer product A, while another person will perhaps prefer product B. The choice is dependent on the value system a person has.

This example shows that the assessment of products can not be completely objective. Natural science cannot determine what seriousness means. This does not mean there is no role for natural science. On the contrary, the role is very important. We need natural science to be able to calculate the relation between the impacts from a product lifecycle and the damages resulting from this. The Eco-indicator methodology thus consists of two parts:

- Natural science is used to calculate damages to the environment caused by the environmental flows from a product lifecycle.
- A valuation procedure is used to establish the seriousness of these damages.

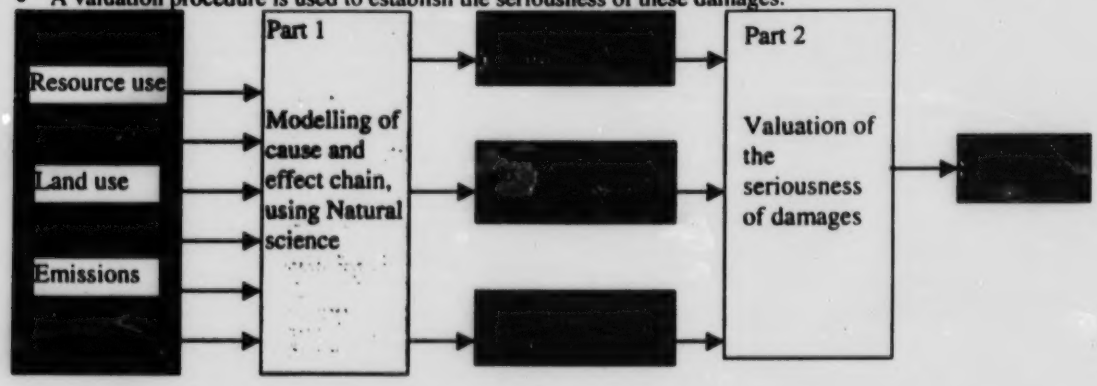

Figure 2. The core concept of the Eco-indicator 97 methodology. There are two parts. In the first part the best available scientific information is used to calculate the average damages caused by an inventory table. In the second part societal preferences are used to assess the seriousness of the damage.
The method is developed in a modular way. Different value systems can be incorporated and it is possible to modify or replace the building blocks used in the natural science part.

3. Calculation of damage

We would not be concerned about environmental problems if these problems did not damage human health, ecosystem health and our resource base. An important feature an Eco-indicator methodology is thus the ability to link environmental problems to damages in the environment. We need to know how much damage to human health would be caused by the emission of 1 kg lead, and how much damage to ecosystems would be caused by the release of 1 kg SO2.

In order to establish this link we must be able to model the cause and effect chain of a substance. That is, we must first understand how an emission is diluted and distributed over the different environmental compartments and how fast it degrades. This type of modelling is called fate modelling. Until now Fate modelling is seldom applied in LCA, However, the work of [Steen], [Jolliet] and [Guinée] show that it is possible, and even necessary to include this step. The result of the fate modelling step is the calculation of the average concentrations in the environmental compartments and in the food and water which people consume.
From these concentrations we can calculate the adverse effects on humans and ecosystems. It is of course very important to define exactly what we mean with damage to human health and ecosystem health. We have found that there are several systems available to describe these damages.
A particular problem is land use changes. It is clear that the damage to the environment is not only caused by emissions. Also the conversion of natural areas into agricultural or urban areas is a frequent cause of damage. In the Eco-indicator 97 methodology the damage from these changes are taken into account when determining the damage to ecosystem health.

The depletion of resources is often also considered to be an environmental problem. In that respect we should differentiate between renewable and non-renewable resources. In the case of renewable resources we cannot say there is a depletion problem on the long range, although it is obvious that there will be problems if the extraction of resources becomes larger than the production.
In the case of non-renewable resources (minerals and fossil fuels) it is clear that there is a limit to the resources. However it is also clear that it is extremely difficult to determine how large the resources are, simply because industry does not explore new resources if the known resources can cover several decades. Another obstacle is that the depletion of a single resource does not have to be a big problem if this resource can be substituted by another resource.
Because of these problems the Eco-indicator 97 methodology does not consider resource quantity, but resource quality.

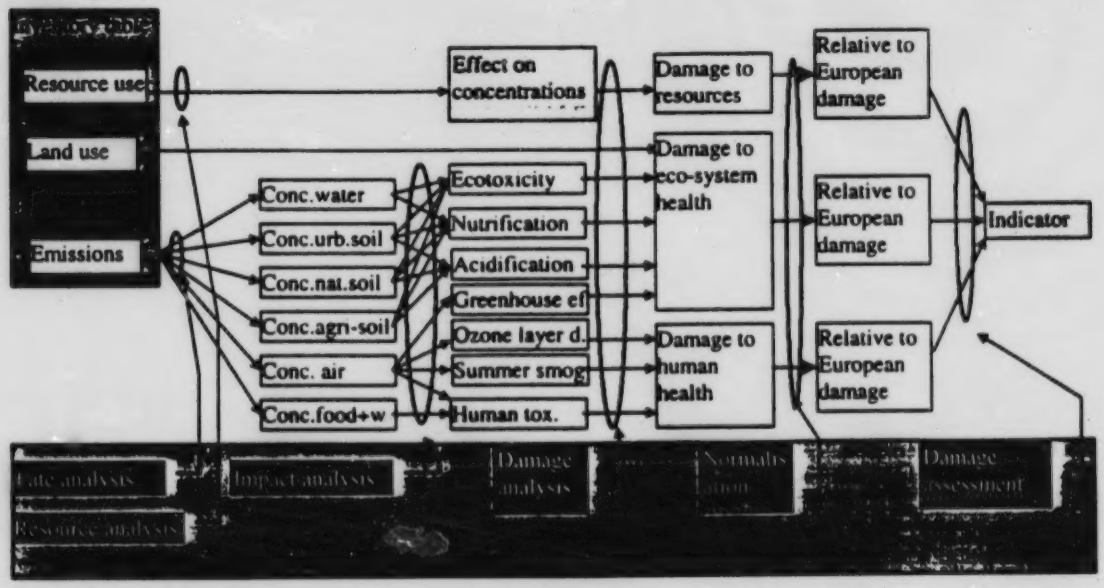

Figure 3 general representation of the methodology The black boxes below refer to procedures, the other boxes refer to (intermediate) results.

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Annexe: Expert team

Name	Employer	Contribution to this project
Bas van Esch	RIVM MNV	Coordinator RIVM contribution
Wilbert Slooff	RIVM MNV	General expert
Gert Eggink	RIVM LCM	Human health
Ton Breure	RIVM ECO	Ecosystems expert
Jan Ros	RIVM LAE	Resources expert
Ruedi Müller Wenk	IWÖ-HSG St Gallen	LCA expert
Patrick Hofstetter	ESU-ETH, Zurich	LCA expert
Stephan Brunner	ESU-ETH, Zurich	Panel expert
Arthur Braunschweig	IWÖ-HSG St Gallen	LCA expert
Reinout Heijungs	CML Leiden	LCA expert
Erwin Lindeyer	IVAM Amsterdam	LCA expert
Hein Sas	CE Delftt	LCA expert
Implementation		
Mark Goedkoop	PRé Consultants	Project leader
Renilde Spriensma	PRé Consultants	LCA expert
Michiel Oele	PRé Consultants	LCA database

LCA introduction

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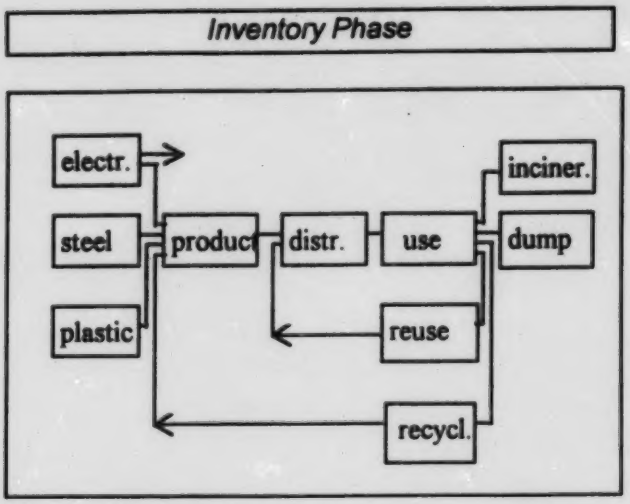
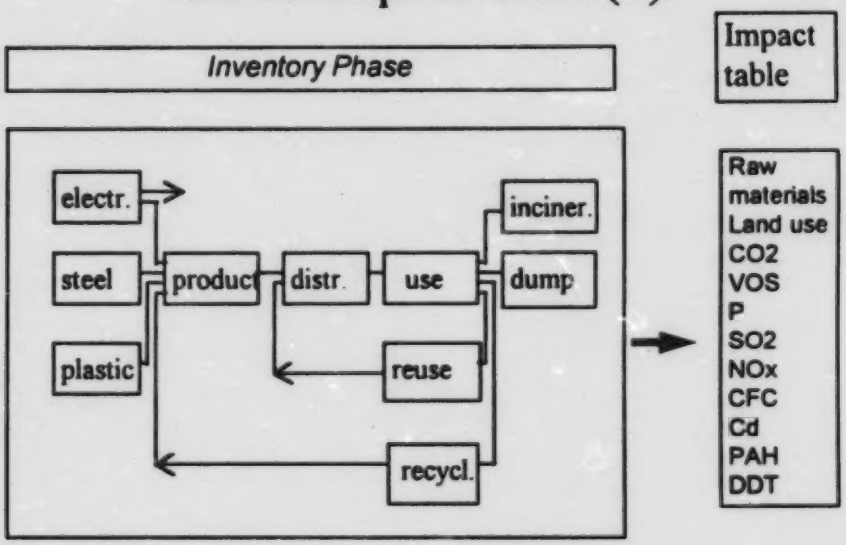
The concept of LCA (1):

- LCA is a model of a complex reality
  - A model of an average lifecycle of a mass product
  - A model of the effect of all impacts that occur
  - Their interaction.
- Any model is a simplification of reality: If you make a model, you must specify the goal and scope of the study first.

The concept of LCA (2):



The concept of LCA (3):



Result of classification (CML)

Result of Normalisation (CML)

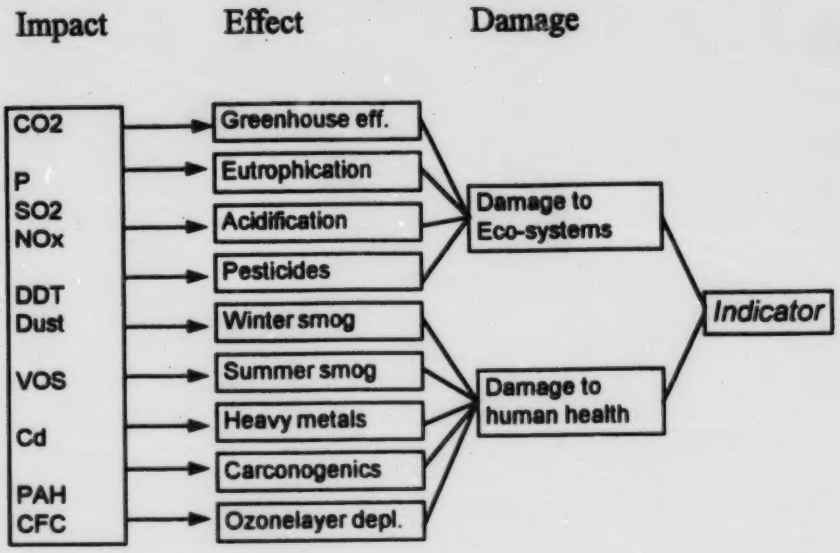
Eco-indicator 95 & 97

- Impact assessment method for LCA.
- Latest available scientific information is used to calculate DAMAGES to the environment:
  - Human health
  - Ecosystem health
  - Resources
- Subjective valuation of damage.

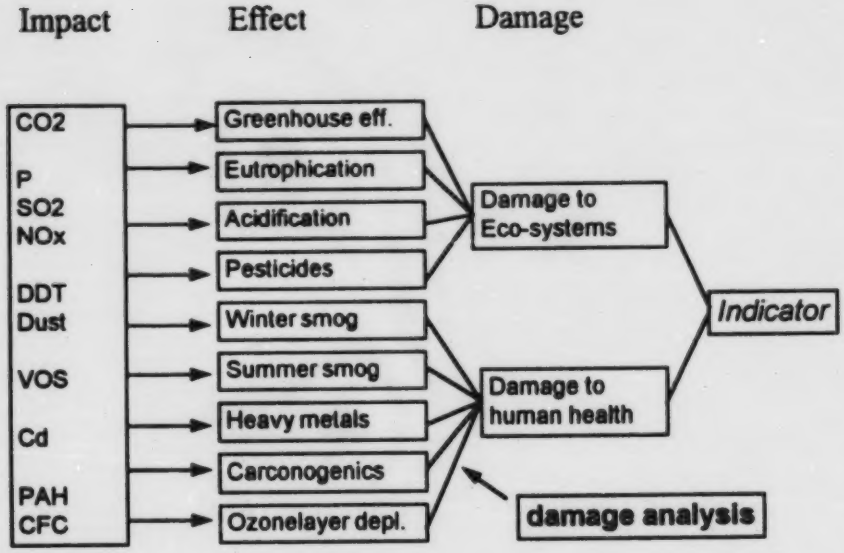
Eco-indicator 95: Parties involved

- Sponsored by the Dutch government, the Noven/NOH programme, after requests from:
  - –Philips Consumer Electronics (BG-TV),
  - –NedCar (Volvo-Mitsubishi)
  - –OCé, (Photocopiers)
  - –Schuurink, (Tumble dryers)
- With advisors from:
  - –CML, IDES, Univ. of Technology. Delft,
  - –Center for energy conserv. , TNO Product Center
- Executed by PRé Consultants

Eco-indicator 95

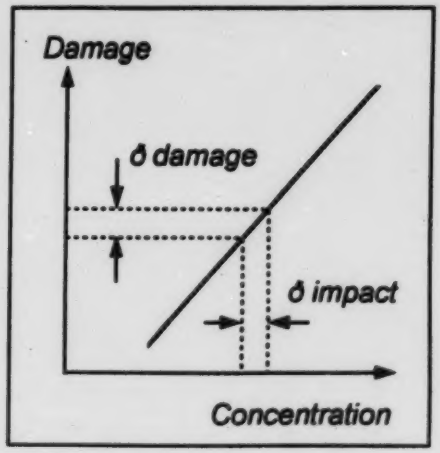


Eco-indicator 95

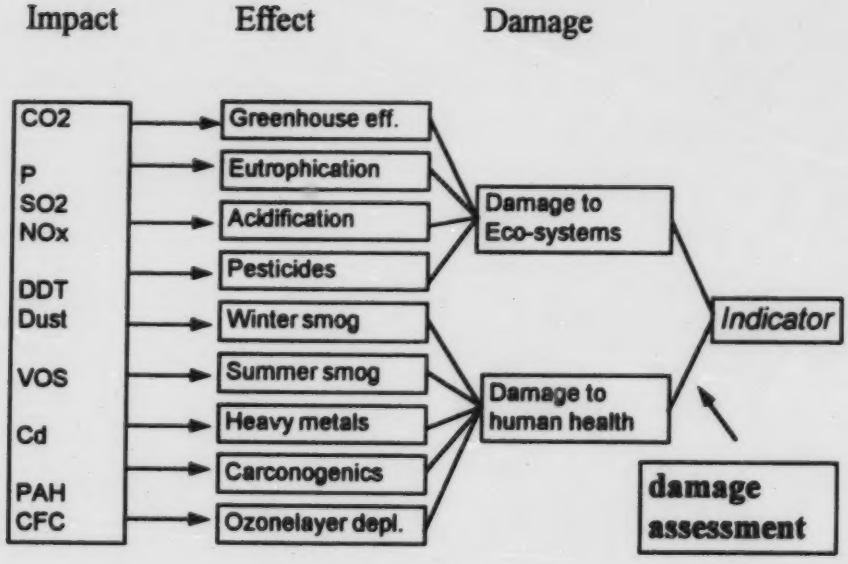


Principle of damage analysis

- Damage function is determined for all impact categories; first derivative (slope) is weighting factor



Eco-indicator 95



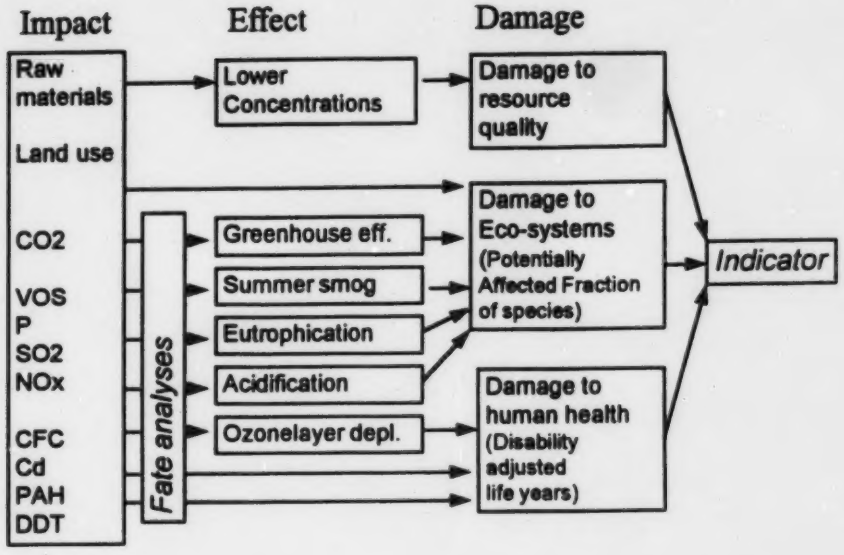
Damage assessment

- The seriousness of a damage type can not be determined objectively
- Panel with representatives from different societal organisations must assess the seriousness of the damage categories:
  - Human health
  - Ecosystem health
  - Resources

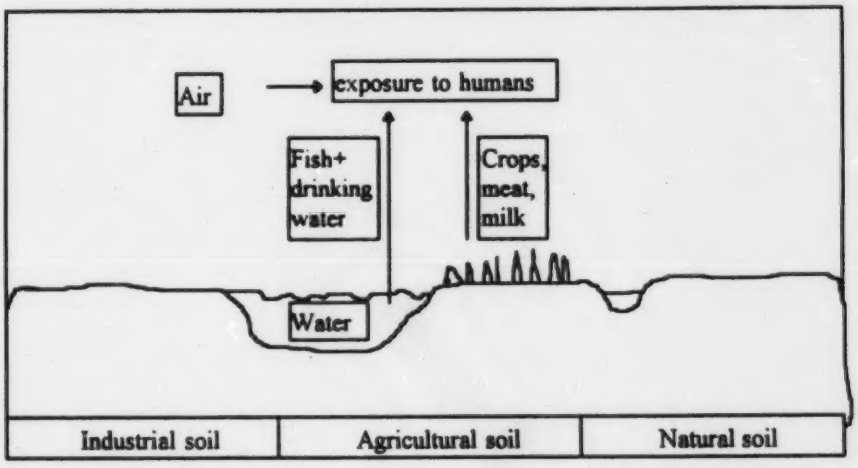
Eco-indicator 97 improvements

- Include depletion of materials and land use.
- Include fate analysis.
- Calculation of 100+ new standard indicators as tool for designers.

Eco-indicator 97



Fate analysis

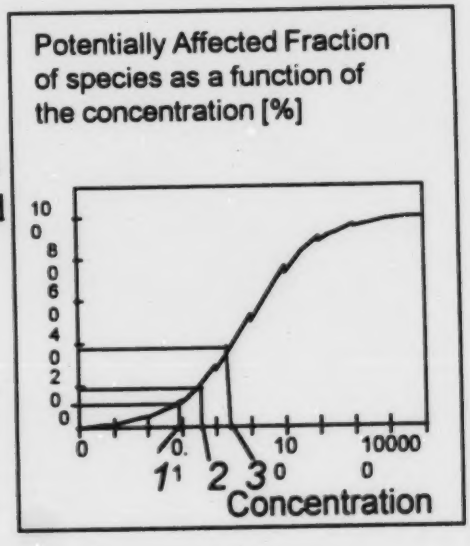


Damage category Human Health

- Disability life years (DALY's) are used from WHO and Worldbank for assessment of health care expenditure.
- DALY system uses disability scale from 0 to 1 (death) and multiplies this with time duration.
- Probably only 20 substances really damage human health. Most important: *Fine Dust.*

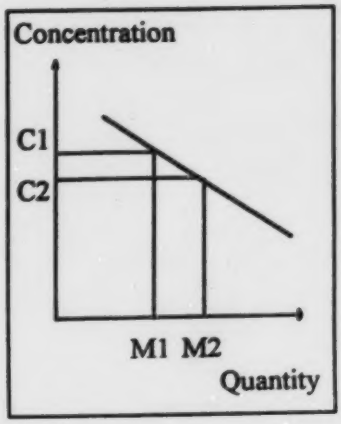
Damage function Ecosystem health

- Potentially affected fractions (PAF) of species, calculated as cumulative EC5 values of lower organisms and plants.
- The slope is the weighting factor.
- The slope depends on background concentration.



Damage function for resources

- A steep decrease in concentration indicates a problem.
- Example:
  M1= extracted before 1950
  M2= extracted before 1990
  C2-C1 is concentration decrease because of M2-M1
- Weighting factor is concentration decrease per ton extracted



International versions

- Eco-indicator 97 can be relatively easily adapted to other regions:
  - Adjusted fate model
  - Different background concentrations
  - Different panel valuation.
- European version will be available end 97
- JLCA forum (MITI, JEMAI and Un. Tokyo) is working on a Japanese version.
- We hope to produce a US version.

Conclusions

- LCA's are complex by definition, but can be simplified
- Impact assessment standard is lacking, but Eco-indicator 95 is widely in use now
- Eco-indicator 97 will have many improvements, but is still only valid for Europe
- The use of damage assessment is getting wide recognition

Development of Life Cycle Impact Assessment Weighting Methodology for Japan - Weighting Methodology Based on Distance-to-Target Principle -

Yasunari MATSUNO, Atsushi INABA, Norihiro ITSUBO and Ryoichi YAMAMOTO

Life cycle assessment (LCA) has received much attention as an effective tool to evaluate environmental burden of a product or service during its life cycle. Many LCA case studies have been carried out in Japan, however, impact assessment has been seldom conducted in most cases. Some of the reasons are that impact assessment has not been well investigated and few weighting methodologies practicable for Japan have so far been developed. In this work, development of life cycle impact assessment weighting methodology for Japan based on distance-to-target principle has been carried out.

The methodology has transparent characteristics and basically follows the SETAC 'Code of Practice.' In global impact categories, the methodology follows the four steps; classification, characterization, normalization and weighting. On the other hand, in local impact categories, the potential impact depends on site and concentration of substances. Thus, site and source type specific consideration is inevitable to get meaningful results. In this methodology, classification and characterization are not carried out for local impact categories. Each substance related to local impact categories is weighted directly by normalization value and weighting factor which are defined site by site. The concept of this weighting methodology is shown in Figure 1.

Among the default list of impact categories suggested by SETAC Europe, six impact categories were taken into account. These are shown in Table 1. Resource depletion, land use, ecotoxicological impacts, odor, noise, radiation and casualties were excluded due to lack of information, limitation of data availability and uncertainty.

Normalization values for global warming, depletion of stratospheric ozone and acidification were mainly calculated with published annual emission data for Japan. For the substances with no emission data available, extrapolation with Dutch emission data was carried out to estimate the emission in Japan. Weighting factors for these global impact categories were derived from the deviation of annual emission from authorized target set by Japanese government. These are shown in Table 2.

Table 1 Impact categories in Distance-to-Target weighting methodology for Japan

Global warming
Depletion of stratospheric ozone
Acidification
Eutrophication
Photo-oxidant formation
Human toxicological impacts

Table 2 Normalization values and weighting factors for global impact categories

Impact category	Normalization value	Weighting factor
Global warming	1.35E+12 (CO_2 equivalent kg)	1.07
Depletion of stratospheric ozone	1.86E+06 (CFC equivalent kg)	1.54
Acidification	2.21E+09 (SO_x equivalent kg)	1

In local impact categories, focused on were 8 substances; non-methane hydrocarbons for photo-oxidant formation, SO_x, NO_x, CO, SPM for human toxicity, COD, T-P, T-N for eutrophication. Normalization value and weighting factor for each substance were defined prefecture by prefecture. The weighting factor for each substance was derived from the extent to which annual average concentration of each substance deviates from the authorized standard. These are shown in Table 3. It was found that annual average concentration of SO_x and CO is below the authorized standard in almost all sites in Japan at present, leading no weighting factors. The concentration of non-methane hydrocarbons, NO_x and SPM exceeds the standard in many prefectures in Japan. Especially, in large city region such as Tokyo, Osaka and Nagoya region, the weighting factors for these substances are large.

Calculation of indicator points has been done with the same inventory for three sites in Japan to show the site-specific differences of indicator points.

Development of Life Cycle Impact Assessment Weighting Methodology for Japan

Yasunari MATSUNO, Atsushi INABA
National Institute for Resources and Environment
Norihiro ITSUBO and Ryoichi YAMAMOTO
Tokyo University

ABSTRACT

Life cycle assessment (LCA) has received much attention as an effective tool to evaluate environmental burden of a product or service during its life cycle. Many LCA case studies have been carried out in Japan, however, impact assessment has been seldom conducted in most cases. Some of the reasons are that impact assessment has not been well investigated and few weighting methodologies practicable for Japan have so far been developed. In this work, development of life cycle impact assessment weighting methodology for Japan based on distance-to-target principle has been carried out. The methodology has transparent characteristics and basically follows the SETAC 'Code of Practice'; classification, characterization, normalization and weighting. Normalization values were estimated for 6 impact categories. Weighting factors for global warming, depletion of stratospheric ozone were derived from the deviation of annual emission from authorized target. In local impact categories, classification and characterization are not carried out, where each substance is weighted directly with the local normalization value and weighting factor. Calculation of indicator points has been done with the same inventory for three sites in Japan to show the site-specific differences of indicator points.

Weighting principle

Distance-to-Target method

Target

Government policies for global warming and ozone layer depletion

Environmental standard by Japanese government for eutrophication, photo-oxidant formation and human toxicological impacts

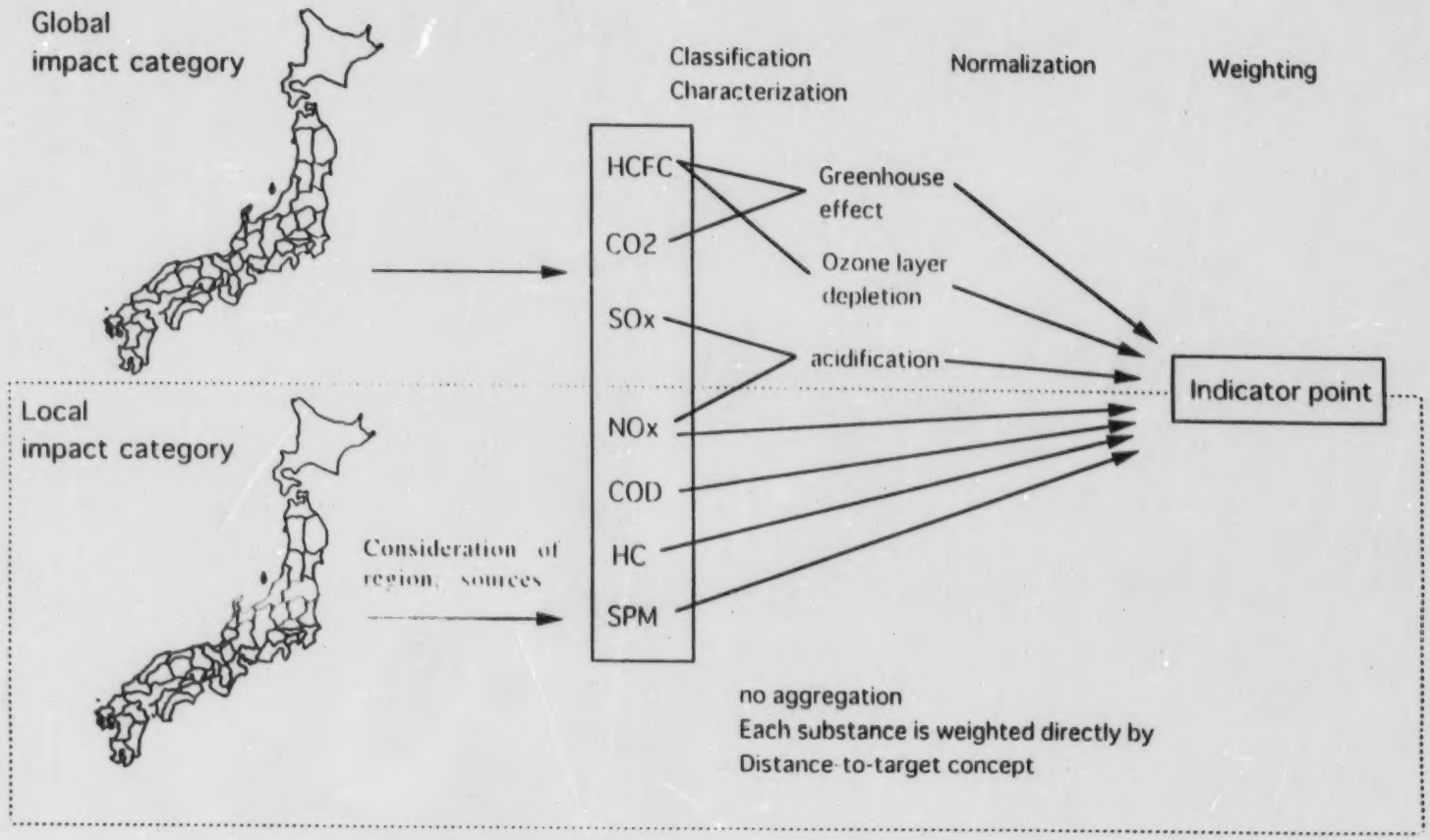


Fig. 1 Concept of weighting methodology

Table Default list of impact categories for LCIA by SETAC-Europe

1	abiotic resources (deposits, funds, flows)	glob
2	biotic resources (funds)	glob
3	land	loc
4	global warming	glob
5	depletion of stratospheric ozone	glob
6	human toxicological impacts	glob/cont/reg/loc
7	ecotoxicological impacts	glob/cont/reg/loc
8	photo-oxidant formation	cont/reg/loc
9	acidification	cont/reg/loc
10	eutrophication (incl. BOD and heat)	cont/reg/loc
11	odour	loc
12	noise	loc
13	radiation	reg/loc
14	casualties	reg/loc

Impact categories

- global warming
- depletion of stratospheric ozone
- acidification
- eutrophication
- photo-oxidant formation
- human toxicological impacts

Table Impact categories and substances in Distance-to-Target weighting methodology for Japan

impact category	substances
1 global warming	CO_2
	CH_4
	N_2O
	HCFC-22
	HCFC-123
	HCFC-124
	HCFC-141b
	HCFC-142b
	HFC-134
	HFC-23
2 depletion of stratospheric ozone	HCFC-22
	HCFC-123
	HCFC-124
	HCFC-141b
	HCFC-142b
	methyl bromide
3 acidification	NOx
	SOx
4 eutrophication	NOx
	COD
	N(total)
	P(total)
5 photo-oxidant formation	CxHx
6 human toxicological impacts	NOx
	SPM

Japanese government policies for
global warming and ozone layer protection

- CO_2; To stabilize at the same level in 1990
  (8% reduction from current level)

- CFCs; Total abolishment by 1996
- Halons; Total abolishment by 1994
- HCFCs; 35% reduction by 2004
- Methylbromide ; 25% reduction by 2001

Table Normalization value and weighting factor for global warming, depletion of stratospheric ozone and acidification

Impact category	substance	Annual emission [ton/year]	Normalization value	Weighting factor
Global warming	CO2	1.26E+09	1.35E+12 [CO2 equiv. kg]	1.07
	CH4	1.38E+06		
	N2O	4.30E+04		
	HCFC-22	2.40E+04		
	HCFC-123	8.10E+01		
	HCFC-124	3.39E+03		
	HCFC-141b	1.43E+03		
	HCFC-142b	2.55E+03		
	HFC-134	7.00E+02		
	HFC-23	1.20E+03		
Depletion of stratospheric ozone	HCFC-22	2.40E+04	1.86E+06 [CFC equiv. kg]	1.54
	HCFC-123	8.10E+01		
	HCFC-124	3.39E+03		
	HCFC-141b	1.43E+03		
	HCFC-142b	2.55E+03		
	methyl bromide	2.38E+02		
Acidification	NOx	1.90E+06	2.21E+09 [SOx equiv. kg]	1
	SOx	8.76E+05		

Environmental standard set by Japanese government

Emissions to air

NOx; < 0.06ppm (Average daily concentration)
SOx; < 0.04ppm (Average daily concentration)
CO; < 10ppm (Average daily concentration)
SPM; < 0.10mg/m^3 (Average daily concentration)
NM-HC; < 0.31ppmC (Average concentration of 6-9 a.m.)

Japanese government policies for prevention of water pollution

- Establishment of environmental standard

  Cd, Pb, As, dichloromethane, dichloroethane, CCl4, BOD, COD, T-N, T-P, etc.

- Area wide total pollutant load controls COD

  Tokyo bay; 8% reduction by 1999
  Ise bay ; 7% reduction by 1999
  Osaka bay ; 4% reduction by 1999

47 prefectures

Fig. Prefecture map of Japan

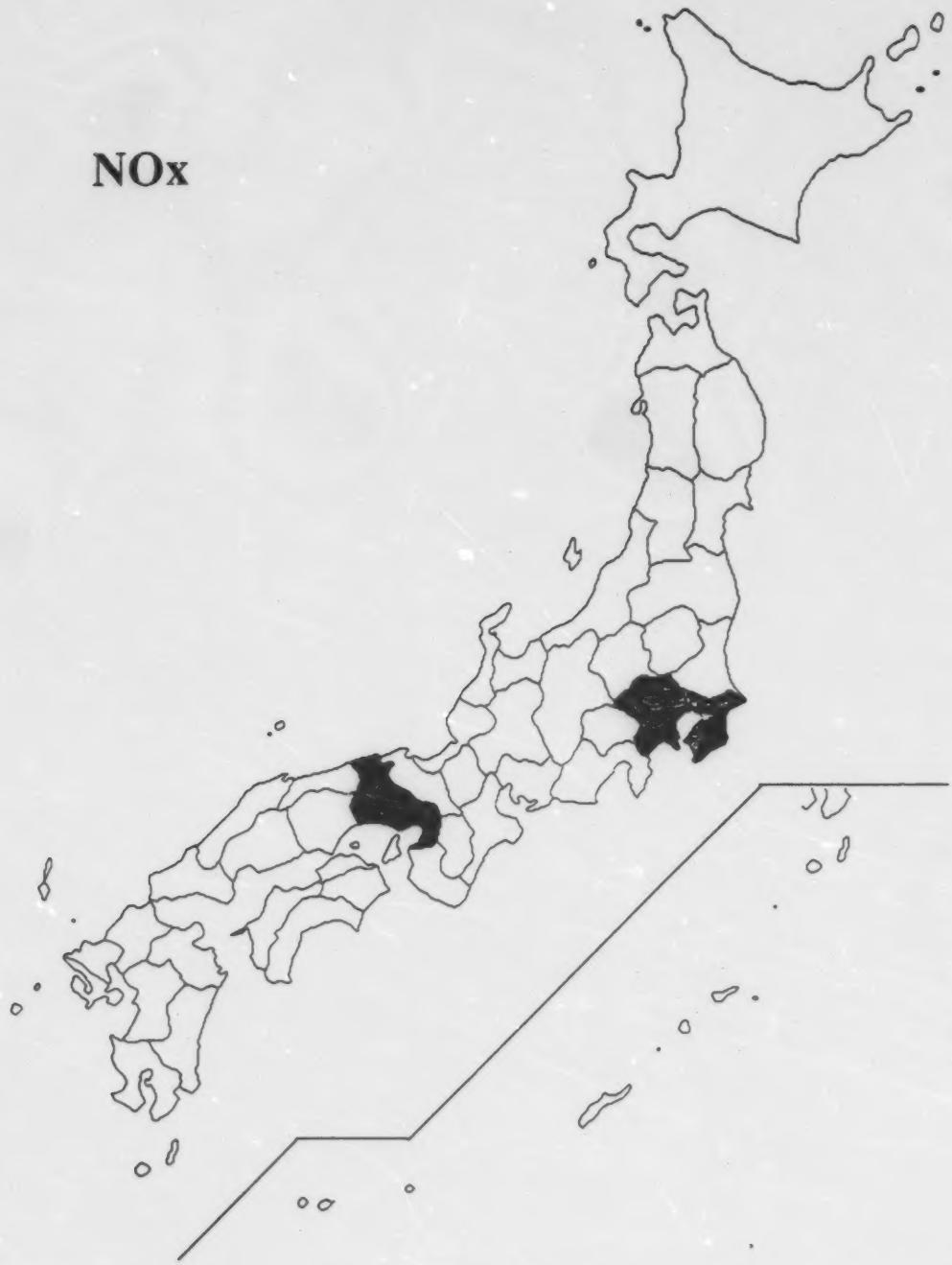


Fig. Prefecture in which NOx concentration is beyond the standard

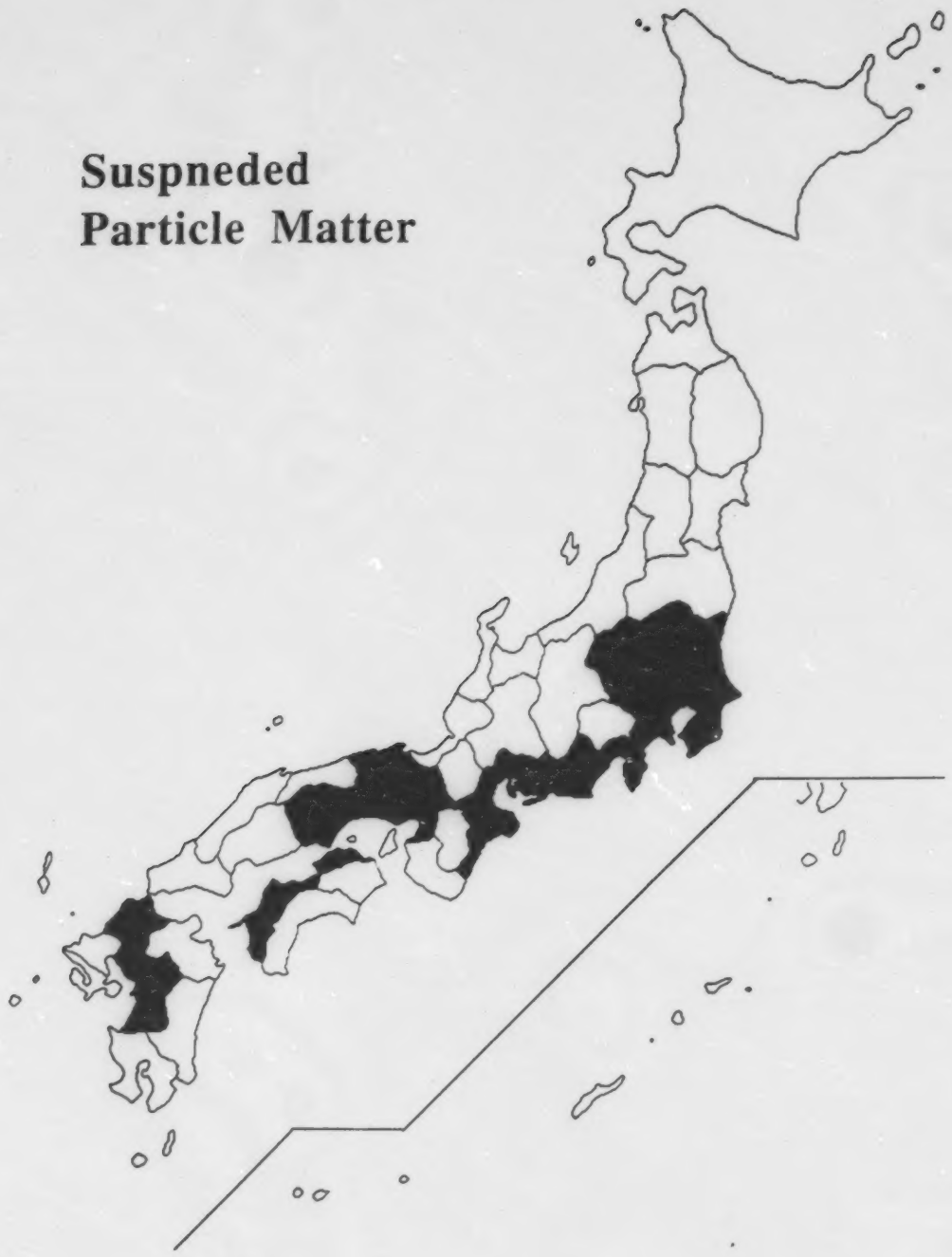


Fig. Prefecture in which NOx concentration is beyond the standard

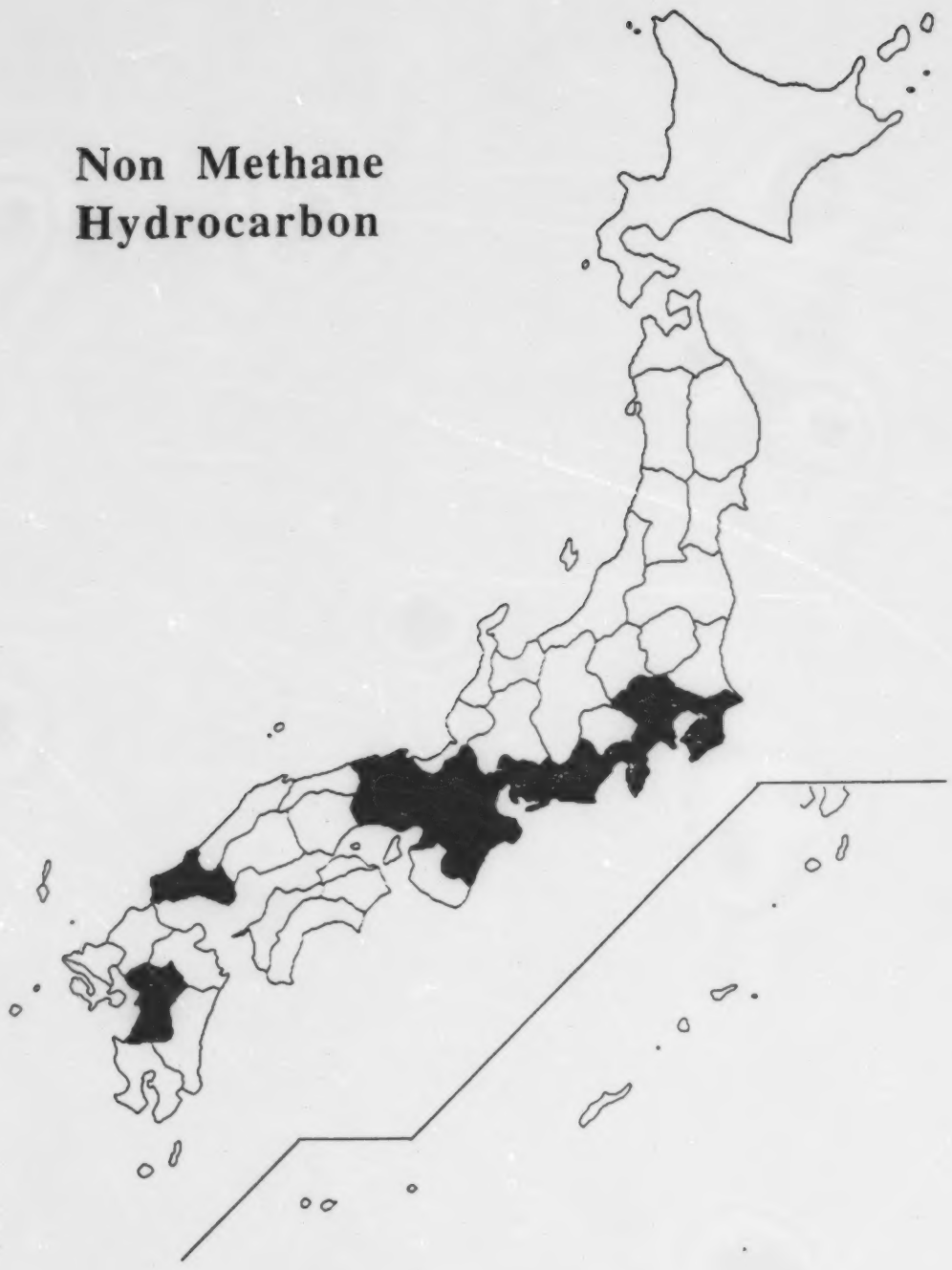


Fig. Prefecture in which NOx concentration is beyond the standard

Table Weighting factor for regional impact categories

Prefecture	photo-oxidant formation	human toxicological impacts		SEA	eutrophication		
	NM-HC	NOx	SPM		COD	T-N	T-P
Ibaraki	-	-	1.45				
Tochigi	-	-	1.18				
Gunma	-	-	1.39				
Saitama	1.87	1.07	1.89				
Chiba	1.48	1.05	1.67	TOKYO bay	1.09	16	16
Tokyo	1.52	1.37	1.56				
Kanagawa	1.71	1.10	1.47				
Shizuoka	1.62	-	1.30				
Aichi	1.35	-	1.27	ISE bay	1.07	1.8	1.9
Mie	1.45	-	1.07				
Shiga	1.16	-	-				
Nara	1.10	-	-				
Kyoto	1.58	-	1.18				
Osaka	1.58	1.08	1.21	SETO-NAIKAI	1.04	3.9	3.3
Hyogo	1.32	1.12	1.24				
Okayama	-	-	1.10				
Yamaguchi	1.10	-	-				
Kagawa	-	-	1.17				
Ehime	-	-	1.17				
Fukuoka	-	-	1.18				
Kumamoto	1.23	-	1.06				

1) -; Negligible

Table Normalization value for regional impact categories

Prefecture	photo-oxidant formation	human toxicological impacts		SEA	eutrophication		
	NM-HC	NOx	SPM		COD	T-N	T-P
Ibaraki	-	-	4.1E+06				
Tochigi	-	-	2.8E+06				
Gunma	-	-	3.1E+06				
Saitama	3.5E+07	5.3E+07	6.8E+06				
Chiba	3.8E+07	8.1E+07	6.0E+06	TOKYO bay	1.0E+08	1.0E+08	8.4E+06
Tokyo	7.7E+07	6.3E+07	9.7E+06				
Kanagawa	4.5E+07	6.6E+07	7.5E+06				
Shizuoka	2.9E+07	-	4.9E+06				
Aichi	3.7E+07	-	8.7E+06	ISE bay	9.0E+07	6.4E+07	6.9E+06
Mie	1.4E+07	-	2.5E+06				
Shiga	9.6E+06	-	-				
Nara	3.5E+06	-	-				
Kyoto	7.8E+06	-	2.6E+06				
Osaka	6.4E+07	5.7E+07	7.5E+06				
Hyogo	2.8E+07	x	5.3E+06				
Okayama	-	-	2.6E+06	SETO-NAIKAI	2.7E+08	2.7E+08	1.6E+07
Yamaguchi	1.8E+07	-	-				
Kagawa	-	-	1.3E+06				
Ehime	-	-	1.8E+06				
Fukuoka	-	-	5.5E+06				
Kumamoto	4.2E+06	-	2.2E+06				

1) -: Negligible

2) SPM: Mobil source only

Table Emissions during the life cycle of a refrigerator

Substance	weight (kg)
CO2	4263
HCFC-141b	0.69
NOx	13.4
SOx	2.57
COD	0.0098
SPM	1.18

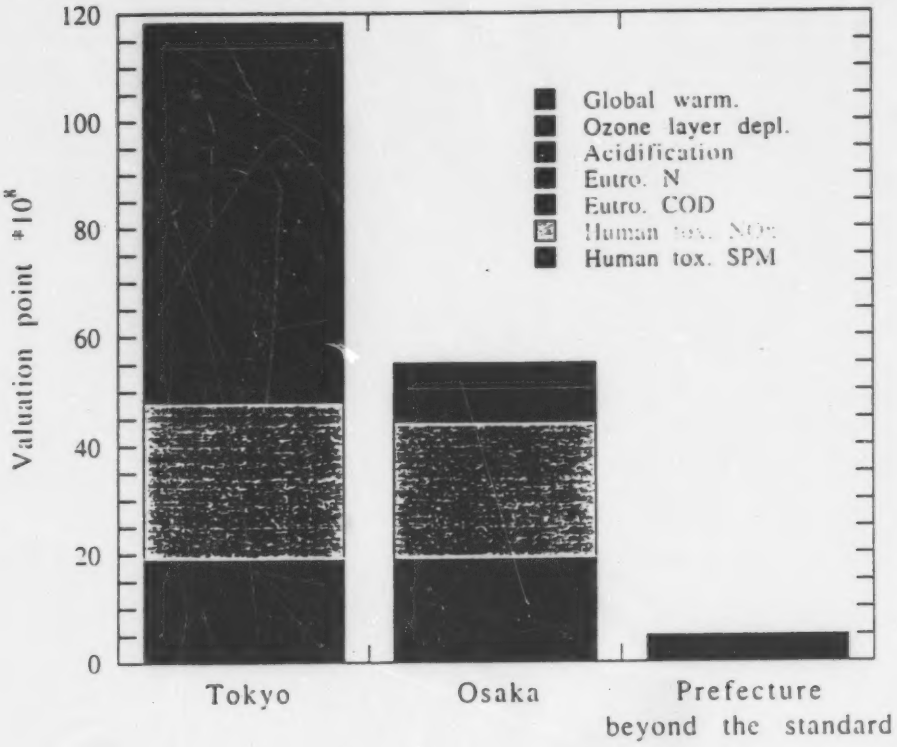


Fig. Valuation point for a refrigerator

ATHENA™: AN LCA DECISION SUPPORT TOOL FOR THE BUILDING COMMUNITY

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ATHENA™ Sustainable Materials Institute

ABSTRACT

This paper gives an overview of the ATHENA™ project and model, including sample results generated by applying the model to a generic office building. The paper highlights a number of key issues surrounding the application of LCA to buildings and the interpretation of results, issues like ensuring functional equivalence, establishing appropriate decision frameworks and judging significance. ATHENA™, an LCA-based environmental decision support tool, helps designers achieve the best environmental footprint by showing side-by-side tabular and graphical comparisons of as many as five separate conceptual designs. ATHENA™ research associates have now completed cradle to site life cycle inventories for steel, wood and concrete structural products, a range of cladding products and gypsum wallboards; have developed a measure of the ecological carrying capacity effects of resource extraction; and undertaken a case study of the energy for building demolition assuming 100% recycling and reuse of structural products and materials. Work on other cladding products, insulation, doors and windows, paints and stains and roofing materials is either underway or planned.

1 INTRODUCTION

Building owners, designers, product specifiers and manufacturers increasingly want to put environmental considerations on an appropriate footing with cost, availability and conventional product performance criteria. But they are hampered by an absence of current, reliable and comparable data in a readily usable form. The ATHENA™ project is developing a practical, easy-to-use decision support tool that will provide high quality environmental data and assist with the complex evaluations required to make informed choices. The ultimate project goal is to encourage the selection of material mixes that will minimize a building's potential life cycle environmental impact.

Initiated several years ago by Fonntek Canada Corp., with the support of Natural Resources Canada, the ATHENA™ project is now being carried out by the ATHENA™ Sustainable Materials Institute, an incorporated not-for-profit organization with membership open to individuals, companies, governments or other organizations.

From the outset we were careful to ensure the credibility of the model and related industry studies. For example, we formed a research alliance involving organizations and people with detailed knowledge about production processes for different building products, the use of those products in building and construction, and broader environmental issues associated with resource extraction and building demolition and disposal. As a result, our work reflects the combined talents of architects, economists, engineers and environmentalists in universities, government and private practice.

One of the first tasks of the alliance was to develop Research Guidelines defining boundary or scope conditions and ensuring equal treatment of all building materials and products in terms of assumptions, data gathering, research decisions, and other aspects of the work. The guidelines have subsequently been published, as have all individual research reports and major progress reports, thereby making the project as transparent as possible. A number of industry associations have participated in the project by providing information and reviewing and commenting on relevant reports at a draft stage.

The project encompasses low-rise commercial, institutional, light industrial and residential buildings. It will eventually encompass all phases of a building's life cycle from the extraction of raw resources to make individual building products, through on-site construction and occupancy to demolition and disposal. In the longer term, we also intend to study and include interior partitions and finishes as well as mechanical and other systems.

Our concern is with direct environmental effects, except in the case of energy where we have introduced upstream resource utilization factors to capture the additional energy use associated with processing, transporting, converting and delivering fuel and energy. We do not deal with the effects of building factories, producing machines, building and maintaining transportation systems, housing workers, or undertaking any of the other activities associated with the basic systems upon which all productive activity depends. We assume buildings will be constructed in specific locations and our objective is to understand the environmental implications of using different combinations of building materials or of altering a building design.

2 OVERVIEW OF THE ANALYTICAL FRAMEWORK

2.1 Life Cycle Stages

A building's life cycle is complex compared to most consumer products. The upper shaded area of Figure 1 depicts the manufacturing and in some cases sub-assembly steps for the wide range of individual products needed to construct a building. This entire process of manufacturing and transporting individual products and sub-assemblies is equivalent to material acquisition for more typical products. Building construction is then equivalent to the manufacturing stage. So we have an additional activity stage in our framework compared to the generic product LCA framework — manufacturing of products and sub-assemblies and then manufacturing of the building itself.

During the occupancy stage we have to take account of functions like heating, cooling, lighting and water use, as well as new products such as paints, stains, floor coverings and other interior finishes. We also have to take account of the fact a building may be remodeled or reconfigured several times over its life (a form of reuse), with changes to interior partitions and possibly the addition of new products or systems. In the course of maintenance, some parts of a building will be altered (e.g. by painting), but other parts may not be seen or touched until the building is demolished.

A building's life cycle ends at the demolition stage, but recycling or waste management activity has to do with the component materials or products, some of which may be reused or recycled, rather than the building as a whole.

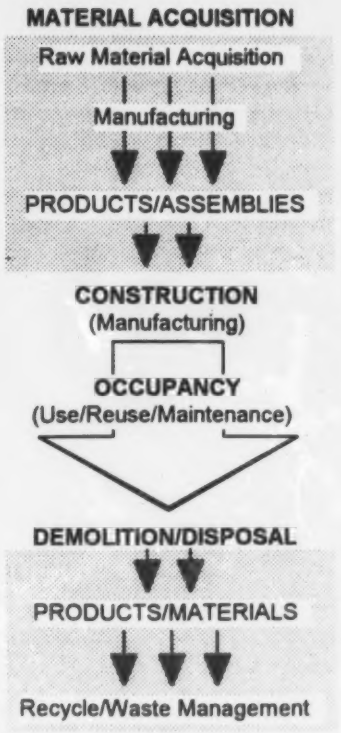

Figure 1. The life cycle stages of a building.

2.2 Inventory Analysis

Inventory analysis is a critical LCA phase during which the inputs and outputs of environmental concern are compiled. As indicated in Figure 2, we eventually have to undertake inventory analysis for every stage in a building's life cycle, including of course the transportation components within and between stages. We need data on the natural resource, energy and water inputs as well as on the outputs or emissions to air, water and land. And we have to look at all products and assemblies individually for the material acquisition and demolition/disposal stages, and in combination for the construction and occupancy stages.

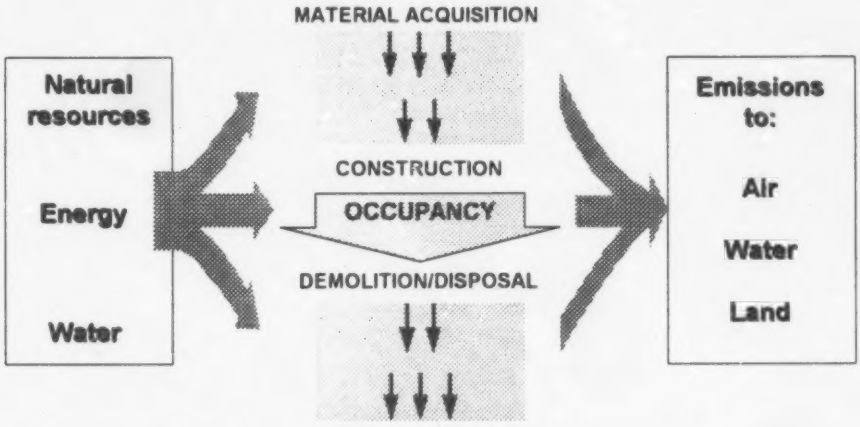

Figure 2. Elements of an inventory analysis

In the ATHENA™ project we start with partial LCIs for all of the individual product and sub-assemblies acquired during the 'Material Acquisition' stage of the building's life cycle — what we might term 'cradle to site' LCIs. Currently, the model contains this kind of LCI data for wood, steel and concrete products used in foundations and in vertical and horizontal structural

assemblies. It also contains LCI data for on-site construction of a building's structural assemblies.

We are now extending to the next logical category, products and assemblies required to complete a building envelope. We have finished the inventory work on gypsum wallboard and on steel and wood cladding products, and are now working on brick and concrete cladding. Future planned LCIs will cover paints and stains, insulation, barriers, roofing, and doors and windows. Completion of the envelope will allow us to properly incorporate operational effects. We have also completed case studies of the energy requirements for building demolition. With the addition of demolition/disposal information to the model we will reach our goal of making available a model that can produce LCA results for complete buildings and the full life cycle. [1] [2]

2.3 Impact Assessment

While the LCI represents an important step toward providing a user with an environmental profile for a building design, we want to go beyond the inventory stage to include impact assessment measures: measures of the ultimate significance in human or other ecosystem health terms of consequences or impacts associated with the inventoried effects.

ATHENA™ is itself an impact assessment tool if we maintain a focus on relative rather than absolute environmental effects and adopt the notion of 'less is better'. We can compare one alternative to another in terms of the inventory results, with a design that gives lower numbers for all categories being preferred. In the more likely case where a design gives relatively poor results in some areas and good results in others, the model user has to make judgments based on criteria from outside the model — a decision to minimize life cycle energy use, for example.

But even this seemingly simple perspective presents problems. For example, it takes considerable expertise to understand the significance of all of the individual emissions to air or water. In the case of raw resource use, there is not even a real basis for comparison from one material to another because a tonne of one resource like iron ore is not at all comparable to a tonne of another resource like timber or coal. Yet the varied effects of resource extraction are a primary environmental concern. Our approach at this point is to provide the following summary measures of potential environmental loading:

- a global warming potential (GWP) index, which aggregates atmospheric emissions that contribute to the greenhouse problem, developed using the CO2 equivalence method;
- air and water pollution indices, developed using the critical volume method for the worst offender, to indicate the relative toxicity or health effects of groups of emissions to air and water; and
- an index of the ecological carrying capacity effects of resource extraction (i.e. effects on the carrying capacity of ecosystems like those of timber harvesting on bio-diversity or the effects of mining on groundwater quality), developed from a survey of environmental and resource extraction experts and used in ATHENA™ to weight the absolute quantities of the main raw resources required to manufacture the products of interest. [3] [4]. Here we have moved from traditional characterization to valuation with the intent of providing a more comprehesive and comparable impact measure.

2.4 Model Operations

ATHENA™ is the mechanism for consolidating all of the LCI data and generating a composite environmental profile for a specific design of all, or part, of a building. A model user first enters

a general description of a building project, including its location, and then specifies a design by selecting from typical assemblies or by entering specific quantities of individual products. Depending on the assembly, the user may have to answer prompts about floor or wall areas, working loads and spans, or other design information. Right now the assemblies are composites of the structural concrete, wood and steel products for which environmental inventory data has been compiled in LCI databases. The location information allows ATHENA™ to determine such aspects as the appropriate electrical grid, the source of building products, and transportation modes and distances.

The model breaks down the selected assemblies into their respective products for the purpose of accessing the LCI databases. In some cases it may consult more than one LCI database because some products use other products in their manufacture or require the use of other products during on-site construction. For example, reinforced concrete and light frame wood trusses use steel components. The LCIs for these concrete and wood products include the quantities of steel products used, but the model looks to the steel database for the related environmental information.

Model results are presented in various ways and levels of detail to meet the needs of different types of users. A researcher wanting detail can see the results by specific energy forms or waste substances, by activity stage and by assembly and product (e.g. the form of energy used to manufacture the nails used in a wood wall). But there are also tabular and graphical summaries of the main categories of inventory data by activity stage for the total design. The model allows the user to make direct tabular and graphical comparisons among as many as five alternative designs.

Our prototype model has undergone limited beta testing in Canada, the U.S. and Europe. The reviews have been more than favorable and we are currently working on a new model version to be released in the near future.

3 SAMPLE RESULTS

3.1 Structural Systems

The Environmental Research Group at the University of British Columbia used ATHENA™ to assess three alternative designs of a typical 4620 m^2 three-story office building with one level of underground parking. [5]

Professional structural engineers were retained to design alternative structural systems using different material mixes, ensuring that each design was appropriate for the building program and location. The building has a relatively simple repetitive structural system, a floor area of 67.5 by 22.5 m exclusive of the stair towers, and a floor to floor height of 3.6 m. All three designs have a concrete foundation and underground parking level, with varying strengths and quantities of concrete depending on the above-ground structure, and with the reinforced concrete elevator shaft as part of the vertical structure.

Figure 3 shows comparative ecologically weighted resource use, energy use, solid waste and global warming potential (greenhouse gas) results for the three designs. The energy, the GWP and solid waste results are broken down in the figure by activity stage — resource extraction, manufacturing and on-site construction. The resource use results apply to only the extraction activity stage.

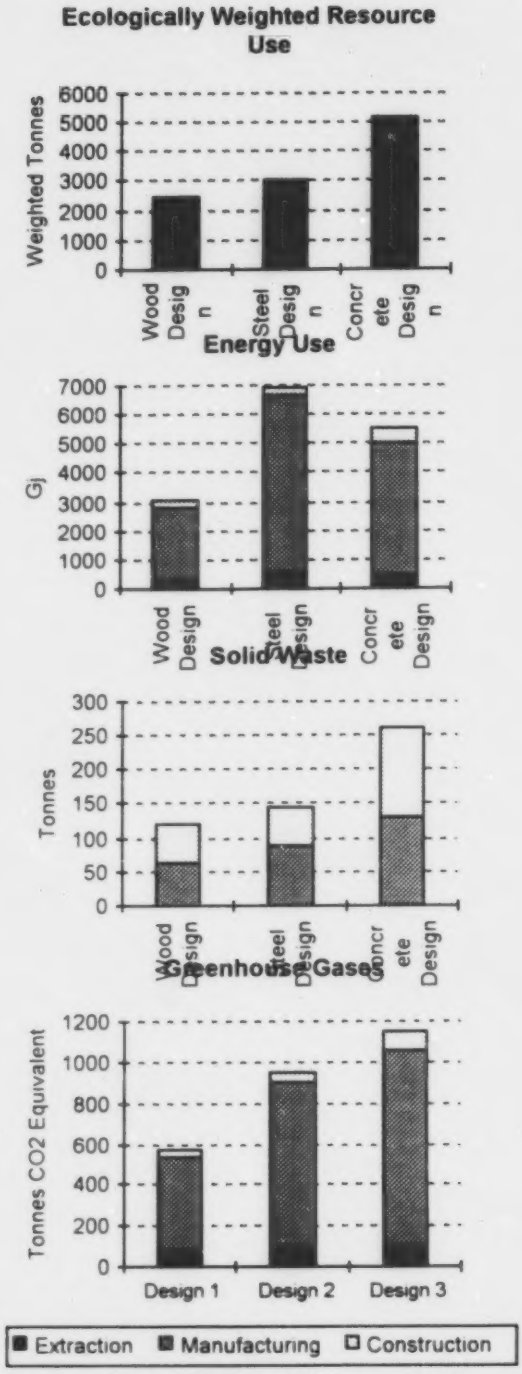

Figure 3. Sample ATHENA ™ results

3.2 Interpreting Results

These results are based on Canadian LCI inventory data for typical or average manufacturing technologies and practices, with the energy use and GWP results taking account of transportation.

We believe the LCI databases and model calculations are accurate to within about 15%, so any comparative results with differences of 15% or less should be treated as equal. That means construction stage energy use, solid wastes and GWP emissions are essentially equal for the example designs 1 and 2, as are extraction stage GWP emissions for designs 2 and 3.

Results like those in Figure 3 have to be interpreted with caution. For example, the principle that products have to be compared on a functionally equivalent basis is well understood when it comes to LCAs for typical industrial or consumer goods. We have to similarly ensure equivalence in terms of such criteria as loads, spans or space enclosure when we compare building products or assemblies. These structural design comparisons meet those kinds of criteria.

Despite ensuring equivalence in strictly structural terms, we do not yet meet a full equivalence test because we are not yet in a position to take account of all the interrelationships among products or assemblies. In fact, we think true equivalence can only be ensured at the level of a complete building design. For example, a wood structure is likely to have different cladding and insulation requirements than steel or concrete, just as concrete and steel structures have different thermal mass and conductivity implications which could affect operating energy. Ensuring functional equivalence for building products is therefore a more difficult problem than it seems and we are only approximating functional equivalence in ATHENA™ because we have not yet encompassed the full range of product groups and activity stages.

We also think LCA results for buildings or building assemblies are better interpreted in a comparative framework. A result like the GWP index, for example, is more relevant as a comparative measure where the comparisons are between assemblies or complete structural designs. Then the model user can see the relative contribution of alternative designs to the greenhouse problem. Otherwise the index would have little meaning unless the user was an expert in the area.

Another interpretation issue that deserves comment is the problem of judging the significance of any given result in terms of the broader scope of environmental concerns. Some argue that LCA results can only be properly interpreted relative to regional or even global inputs or outputs of the measure of interest. Our concern is that results for even a complete building can seem trivial in terms of regional, national or global measures. It is the total of all building construction and operations that is significant in terms of virtually any measure and we should therefore be careful not to impose yardsticks that downplay the significance of improvements. We could instead compare the environmental profile for a given building or assembly design to benchmarks that represent typical or best known practice for a given geographic area.

We should also be aware of the critical importance of temporal issues for long-lived durables such as buildings. For instance, should we simply aggregate effects that occur over years and decades, or look at ways to discount future effects and generate the LCA equivalents of present values, as some advocate? Or should we reject such approaches because they tend to sell out future generations by downplaying future environmental burdens? We believe this to be a pressing issue if life cycle assessment is ever to live-up to its namesake.

4 CONCLUDING COMMENTS

ATHENA™ by and large uses a characterization assessment method to compare and interpret alternative design scenarios. It does not produce any kind of overall environmental

score or rating and we do not advocate that kind of aggregation at this stage in the development of such approaches. This is not to say we disagree with eco-labelling or eco-indicators. But right now we think eco-labelling/indicators should be on a multi-criteria basis, profiling relevant environmental inputs and outputs just as food labels profile ingredients considered relevant from a nutrition perspective.

We applaud the eco-indicators initiative and would not hestitate to adopt eco-indicators as one environmental measure available within the ATHENA™ model if it becomes an accepted evaluation standard. But we should keep in mind that eco-indicators is an evaluation method to be applied to properly characterized LC inventory data. It is not a model in the sense that ATHENA™ or SimaPro are models for conducting LCA investigations. The value of eco-indicators like any other evaluation method, or characterization for that matter, depends on the quality of the basic inventory data on which it must ultimately be based. Our focus continues to be on the development of that data and on resolution of the related issues.

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LIFE-CYCLE-ENGINEERING: REQUIREMENTS AND LIMITATIONS OF INDICATOR AND DFE-TOOLS

Martin Baitz [1], Konrad Saur [2], Johannes Kreißig [1]

[1] IKP, University of Stuttgart; [2] PE Product Engineering GmbH, Dettingen/Teck

In the last decade ecological aspects of product systems were integrated in the assessment of materials, processes, products and services by Life-Cycle-Assessment. LCA has been identified as a tool able to generate reliable information of complex systems. The need to transfer the knowledge of this analysis into decision making processes in industry and policy (merging with social, economical and technical aspects) is obvious and led to the Life-Cycle-Engineering approach and should further be developed to an DFE-Tools, able for their company decision making support. Those tools have to deal with different demands: easy-to-use, fast, plain and reliable results while characterising a complex reality.

The result is influenced mainly by the system boundaries and boundary conditions of the inventory and by the use of different value systems in selecting and weighting of impact categories. The need to aggregate impact categories is obvious in the application of Eco-Design-Tools (EDT), but not necessarily to identify the "greenest" product.

The pretension of LCE to identify weak-points and show optimisation potentials in design has to be satisfied also by an EDT. Reducing ecological optimisation of products during the design phase to the choice of different materials is to avoid, as the influence of different processes leading to the same material (of different suppliers), application of materials, distribution situations and the construction itself may influence the ecological impact of a product more significant, as the production of the material. An example is coating, as the application dominates the ecological relevance, because of energy

demand and used energy supply, rather than the production of different varnish materials.

A DFE-Tool has to reflect different sectors with their specific situation (energy supply, material efficiency, market, region, ...) to get information in a sufficient precision for setting up reliable eco-profiles of products. Reducing the problem to general materials and general processes suggests something not existing: general fix eco-profiles. As specific industrial sectors are analysed, an EDT should provide a profile of the utilisation phase as well, because the designer is not able to set it up and Life Cycle Tools have proved their specific strength in systemwide assessments. Transparency and flexibility of the model is obvious and important.

To describe the ecological relevance of products potential impacts have to be chosen. Potential impacts are a kind of worst case assessment. As long as not all cause-effect-relations of ecological relevant emissions or actions are scientifically established, an effect or damage calculation is daring and may lead not to ecological optimisation

Effects and interactions within a hyper-complex system like the ecosystem, which are neglected or arbitrary assigned in today's cause-effect-models may influence the system and change the results. Therefore potential impacts are to set up, which have to be normalised on a world level, because the product system and it's emissions often are spread over the globe. "Default" weighting parameters, which can be modified by the user (company ideology, national situation), have to be integrated Thus an individual esteem of the decision-maker is represented, as he is responsible for the ecological impact of his product.

Research at the field of weighting methods and the relation between cause, effect, damage and safeguard subjects are very important parts of environmental science, but as long as those models base on too many assumptions and uncertainties, known approaches should secure the desired ecological optimisation.

Toronto '97

Eco-Indicators for Products and Materials

Life Cycle Engineering - Requirements and Limitations of Indicators and DFE-Tools

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Key Words: Decision Support, Science vs. Consensus, ISO 14040f

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Life Cycle Considerations

- Life Cycle Analysis covers the environmental aspects over a system life cycle.
- LCA does not include technical and economical aspects.
- LCA and LCE/LCC are aiming at supporting better informed decisions.
- LCE consists of LCA, economical and technical criteria.
- LCE is aiming at design and decision making support.
- 1st level: improvement or weak point analysis
- 2nd level: design support
- Need for the full picture

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Why Life Cycle Considerations?

- Identify possibilities to improve the **system** under consideration. LCA is the only tool providing the system perspective.
- LCA includes **different media**: releases into air, water, soil and resources.
- Collect and interpret material and energy flows for **optimization** and decision making support purposes.
- Ensures a reliable **decision making** basis.
- Replaces today´s defensive (regulatory based) environmental protection approach by a **preventive** (offensive) approach.
- Identification of material and energy flow optimization reveals **economical optimization** potentials as well.
- **Prevent** inefficient and "improvements" or "optimizations".
- Manage product stewardship or product **responsibility**.

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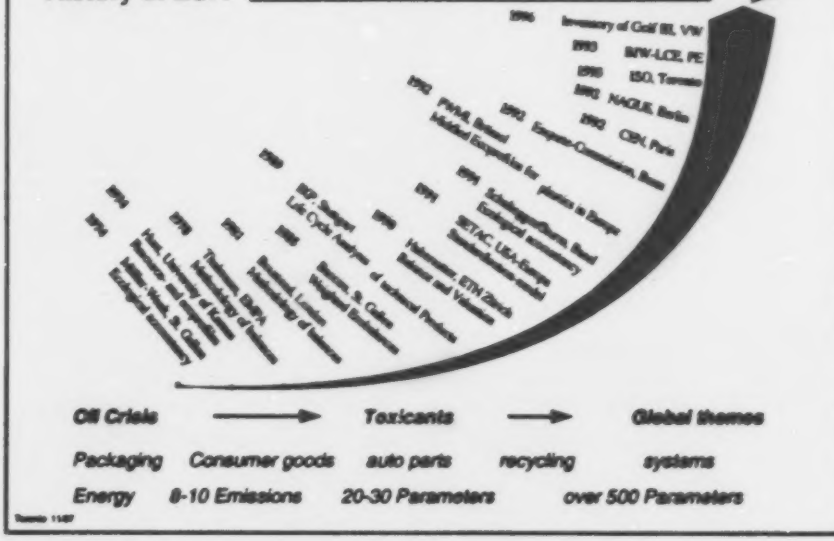
History of LCA



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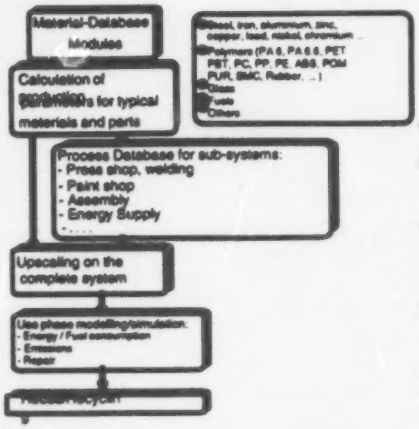
System Modeling



- Modular Structure:
  - Materials
  - Energy (Power, Steam, Fuel)
  - Processes (Production, Assembly, Recycling, ...)
- Piece List Analysis
- Selection of representative parts and processes/materials
- Simulation/Measurement of actual Material and Energy Flows for selected parts (Products, Emissions, Sewage, Waste, Power, ...).
- Life Cycle Modeling
- Analysis
- Identification of "Hot Spots"
- Decision Support

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Decision Making Support

Requirements:

- Decision Support under Uncertainties
- Decision Support in a dynamic environment
- Quick response
- Easy-to-use
- Reliability
- Multidimensionality
  - technology
  - economy
  - environment
  - social aspects
- Possibility to consider individual situations
- ...

Solutions:

- Fast Performance of full analysis instead of screening
- System view instead of single process stage view.
- Knowledge based solutions instead of assumptions.
- Multidimensional Solutions: LCE
- Optimal Product or Process instead of "green" niche solutions.
- Transparent solutions.
- Flexible and easy to change assumptions and values.
- Client specific scoring methods.

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Impact Assessment

- Environmental Interventions occur in time lag, in different places under different chemo-physical conditions.
- Aggregating of interventions to equivalents in impact categories reflects a possible potential of an effect
- Actual reactions and impacts of those interventions can't be described
- Less cause-effect-relationships of the impact-network to the safeguard subjects are known
- Isolating known single cause-effect-relationships may lead to misinterpretation
- Safeguard subjects have to be identified by societal panels and have to be accepted
- **Conclusion**: worst case estimations needed (impact potentials) flexible transparent weighting needed

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ECO-Design Tool
- Structure

- variety of reliable ready-for use inventory modules for materials, processes and systems
- flexible impact assessment
- various weighting sets and values systems
- scenario technique is a must
- sensitivity analysis: ranges
- uncertainty analysis: ranges
- in depth analysis: weak points, contribution and dominance
- sector specific situation considered
- **computerized tool**
- **knowledge based**

- **Service** functionality
- Not only profiles of **materials**
- allow **complexity**
- **contribution** of life cycle stages and single processes are important
- **client** specific solutions must be possible
- no **automation**
- **user responsibility**
- **weak-point** identification possible

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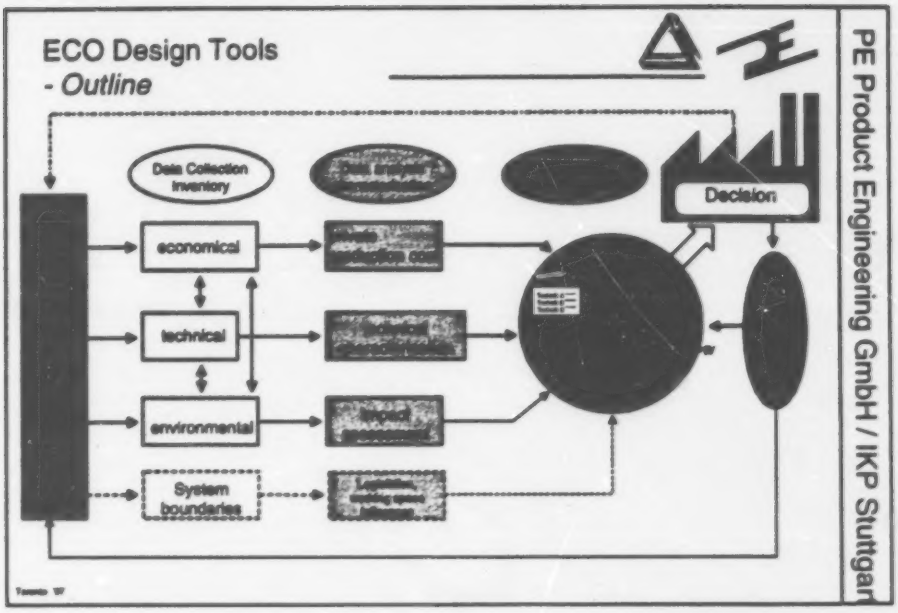
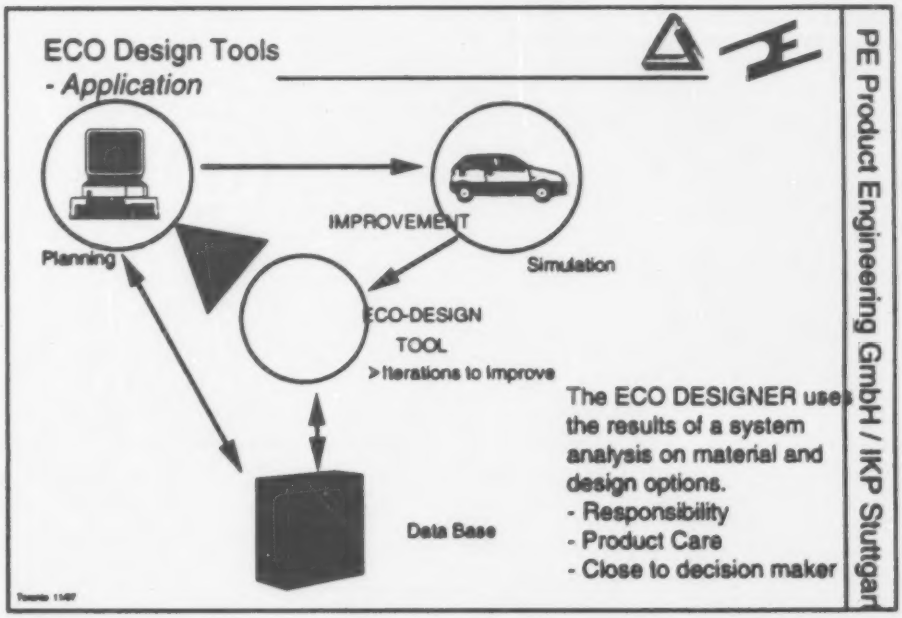
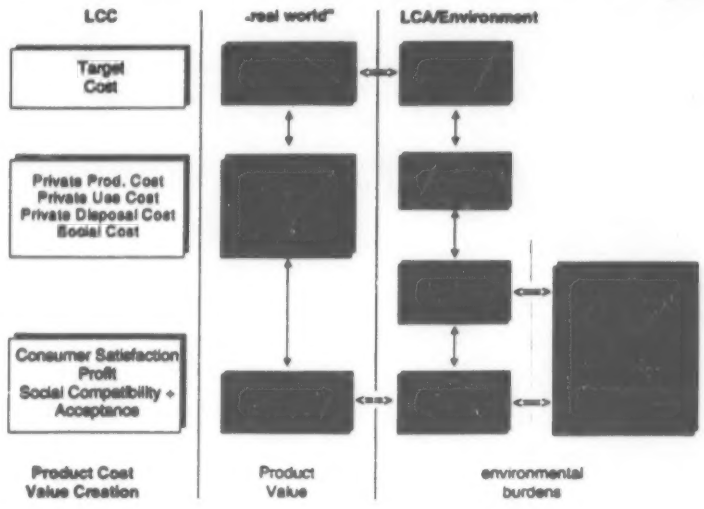

ECO Design Tools
- Outline
Data Collection Inventory
economical
technical
environmental
System boundaries
Decision
PE Product Engineering GmbH / IKP Stuttgart


ECO Design Tools
- Application
Planning
IMPROVEMENT
Simulation
ECO-DESIGN
TOOL
> Iterations to improve
Data Base
The ECO DESIGNER uses the results of a system analysis on material and design options.
- Responsibility
- Product Care
- Close to decision maker
PE Product Engineering GmbH / IKP Stuttgart

Life Cycle Engineering - a Toolbox-Concept



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Conclusions

- The **use phase** can be considered as decisive with respect to energy and combustion emissions like CO2.
- For other emissions and environmental problems (e.g. heavy metal emissions, hydrocarbons) the material **production** or the **processing** are relevant or even dominating.
- **Recycling** partially has great significance.
- From the environmental and economical perspective there are no good or bad materials as such. The related **design** and production has to be the subject of the considerations.
- Life Cycle Considerations can be an important **decision support** tool.
- **Overall improvements** can also be achieved by "investments", economically and environmentally.
- **Overall** optimization needs the **System Perspective**.
- **Environmental** Considerations reveal also **economic improvement** Options.
- **Safeguard-Subjects** not defined, flexible weighting obligatory as the designer or company is responsible for the product.
- **Higher level of responsibility** for the ECO DESIGNER due to multidimensionality

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A Technical Framework for Life-Cycle Impact Assessment and Its Potential Application in Measuring the Degree of Sustainability of Industrial Systems

Stanley Rhodes and Linda Brown

Over the past four decades, the importance of balancing economic interests with human needs and the environment has become increasingly apparent. Internationally, this recognition has coalesced around the concept of "sustainable development," the watchword of the 1992 United Nations Conference on Environment and Development (UNCED). In follow up to the UNCED summit, government planners, businesses and stakeholders groups have worked to develop "sustainable" strategies integrating environmental considerations with economic development. While making much progress, these strategies have nevertheless been hampered by a lack of objective tools with which to measure "sustainability."

The field of life-cycle assessment (LCA), with its systems-oriented, cradle-to-grave scope of assessment, is one important scientific tool for examining the question of whether sustainability can be determined on a quantitative basis. The development of a technical framework for life-cycle impact assessment is a clear stepping stone in the eventual assessment of the sustainability of industrial systems.

This paper reviews current developments within the area of LCA and life-cycle impact assessment (LCIA), then concludes with a discussion of some key issues that would have to be addressed in the eventual assessment of sustainability..

1. Historical Context

1.1. Development of LCA Practice

Life-cycle assessment (LCA) was first developed during the energy shortages of the early 1970s as a systems-oriented tool for tracking energy flows in industrial systems. Emerging out of the science of through-put analysis, LCA was essentially an extended input/output analysis resulting in an overall mass and energy balance across a "cradle-to-grave" scope. The assessment is structured around the linking of unit processes (unit operations) involved in the extraction, production, distribution, use and disposal of a product or service performing a useful function.

The key procedures are:

1) identifying unit operations comprising a defined system;
2) collecting input and output data for each unit operation;
3) allocating input/output data, typically by mass, among co-products of a given unit operation;
4) aggregating input/output data, again on a mass basis, across unit operations; and
5) normalizing aggregated/allocated input/output data to a functional unit.

Figure 1 depicts how unit operations are linked and input/output values are aggregated into a cumulative mass and energy balance.

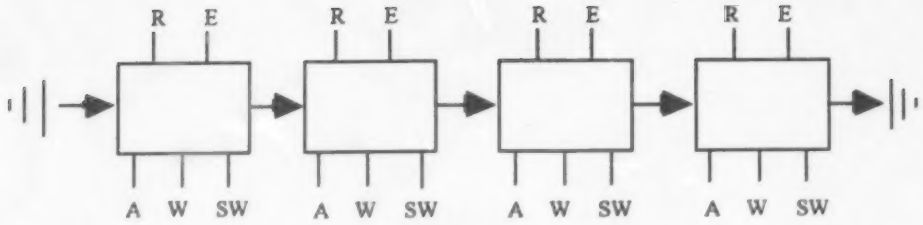

Figure 1 — Simplified schematic of linked unit operations in industrial system[1]

Several computer models have been developed in Europe and the US to conduct the life-cycle inventory (LCI) calculations needed to complete these extended mass and energy balances. Over time, these models have been extended to include data pertaining to a range of emissions and wastes to air, water, and ground.

1.2. SETAC LCA Technical Framework

In an effort to harmonize the methodologies and resulting databases of the various models, the Society for Environmental Toxicology and Chemistry (SETAC) set out in the late 1980's to bring together leading practitioners and other interested scientists and policy makers to facilitate the development of the science practice and application of LCA through a series of workshops. In 1991, SETAC published the proceedings of the first workshop, in which a technical framework was proposed. Under this framework, LCA was described as having three separate components: inventory, impact assessment and improvement assessment (Fig. 2). In later workshops, a fourth component — goal setting and scoping — was added to the framework.

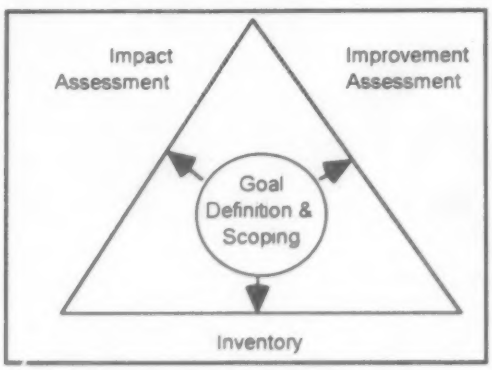

Figure 2—
SETAC Technical Framework for LCA

This framework, in turn, became the starting point for LCA standardization work within ISO TC-207. The mass and energy procedures of the inventory phase described in the SETAC monogram, *A Technical Framework for Life-Cycle Assessment* (1991), have been subsequently formed the basis of LCI standardization in ISO DIS 14041.

[1] R= Resources, E = Energy, A = Emissions to Air, W = Emissions to Water, SW = Solid Waste

The decision to include "impact assessment" as a distinct stage within this technical framework reflected a recognition of the growing interest in evaluating life-cycle inventory (LCI) data within an environmental context. Subsequent SETAC workshops, meeting presentations, and publications have explored the issues and obstacles involved in conducting impact assessment, and together with the Nordic Council and others, have laid the necessary foundation for the framework discussion presented in this document.

1.3. Limitations in Conducting Impact Assessment based on Mass and Energy Inventory Approach

As stated in the SETAC publication, *A Conceptual Framework for Life-Cycle Impact Assessment* (1993):

> "One of the most significant findings presented in the *Technical Framework for Life-Cycle Assessment* is the recognition that the complexity of environmental issues requires a more sophisticated approach than just quantifying materials and energy use, along with airborne, waterborne, solid waste and other environmental releases, as has been done in previous LCAs."

The publication goes on to describe impact assessment as an assessment of "potential and actual environmental and human health effects related to the use of resources (energy and materials and environmental releases."

Over time, however, the difficulties in conducting life-cycle impact assessment from the aggregated, allocated, and normalized inventory data of the mass and energy balance have become accepted within SETAC and among LCA practitioners and users. The inventory procedures, established for the purpose of tracking material and energy flows, were not established for purpose of linking system inputs and outputs to actual effects on the environment. As a result, the current draft life-cycle impact assessment standard (ISO 14042, CD for ballot) now includes the following statement: "life-cycle impact assessment does not identify, measure, predict or represent actual environmental impacts or surpassing thresholds, and is not a measure of safety margins or risks."

The key factors limiting the use of the mass and energy framework in conducting impact assessment have been summarized as follows:

- By containing the life-cycle inventory (LCI) analysis within the physical perimeters of the system's unit operations, the framework does not provide a method for linking an industry's inputs and outputs to actual environmental effects.

- The process of aggregating and allocating data removes some of the key spatial and temporal resolution of the input/output data — namely, their relationship to a particular location, and to a particular time of onset and period of duration. Such data treatment precludes the development of linkages to actual environmental impacts, since impact models must reflect environmental mechanisms which are, in turn, spatially and temporally dependent. These models (e.g., fate and transport) are necessary for calculating threshold levels and other dose-response relationships.

- The selection of the functional unit under the mass and energy framework does not take into consideration the size or scale of production occurring at the various unit operations within the scope of a study. Nor does this selection take the location of these operations into account. As a result, the environmental significance of releases cannot be determined. (For instance, a functional unit of one kilogram of paper does not reflect

the actual production scale of a modern paper making machine (typically 200,000-400,000 tons of paper annually), and thereby cannot reflect the actual environmental effects.)

- The framework provides no objective procedures for selecting life-cycle impact indicators (global, regional and local).

- The framework is based on assessment of elementary flows, and as such precludes the ability to address impacts associated with an industrial system's land use, including impacts on biodiversity and habitats.

Efforts within ISO 14000 to standardize LCA practice have helped to highlight these inherent limitations. As mentioned above, the draft life-cycle impact assessment standard (14042) now disclaims the ability to relate inventory data to actual environmental impacts.

Depending on the goal and scope of the LCA study and its expected use, the commissioners of the study have often found it necessary to evaluate the environmental significance of LCI results. In the absence of a scientifically-based technical framework for life-cycle impact assessment, the LCI data tend to be treated using a number of interpretative procedures (included in CD 14042 and CD 14043) which are largely value-based. These procedures include, but are not limited to, indexing, weighting across impact categories, and indicator ranking schemes.

The last phase of the SETAC framework, improvement assessment, has been eliminated from the ISO LCA standards. Its intended replacement, "interpretation assessment," does not address improvement assessment or valuation, and lacks a common or historic practice.

These trends have suggested strongly the need for an expanded technical impact assessment framework — one that is still rooted in fundamental life-cycle principles and retains the quantitative nature of input/output data system, but that also integrates the basic principles, procedures and data of impact assessment sciences (e.g., risk assessment and environmental impact assessment).

2. A Conceptual Framework for Life-Cycle Impact Assessment

The SETAC Sandestin workshop, summarized in the 1993 publication, *A Conceptual Framework for Life-Cycle Impact Assessment*, a number of important contributions toward the development of a technical life-cycle impact assessment framework.

These contributions included

- introduction of the stressor concept as the key bridge between the inventory and impact components of LCA,

- descriptions of the linkages between stressors and impacts through "stressor-impact chains;"

- recognition of the need for spatial, temporal and threshold characterization of input/output data;

- recognition of the necessity for impact indicators, and the issues in choosing and calculating these indicators; and

- recognition of impacts not included in life-cycle inventory, such as impacts related to land use, noise, and thermal releases.

Stressors were defined as environmental releases or other disturbances associated with industrial systems that may lead to human health, ecological and resource depletion impacts." Stressor-impact chains (also called "stressor-effects networks") were recognized essentially as descriptions, or models, of the environmental mechanisms (physical, biological and chemical events), which link specific system inputs, outputs or activities (i.e., the "stressors") to observed impacts on the environment (Fig. 3). Many of these environmental mechanisms have been extensively studied over the years. Stressor-effect networks may be simple (a single stressor related to a single effect), but most often, are complex (with multiple stressors and/or effects).[2] Intermediate effects, biological processes, or chemical processes, called "nodes", can be identified along the environmental pathway between the initial stressor (input/output) and the endpoint effect(s).

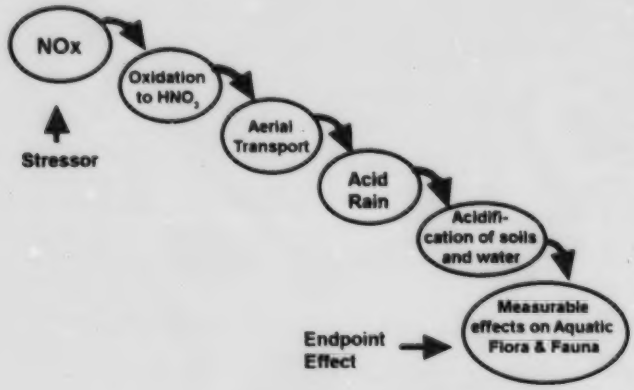

Figure 3 — Simplified acidification stressor-effect network

At the same time, the SETAC monogram identified important areas of additional research for future technical framework development:

- Setting appropriate boundaries at the outset of the project and iteratively reviewing these boundary conditions;
- Stressor-impact chains and their implications along the life-cycle;
- Additional characterization data needs, including the need to "determine whether or not methods developed for human health and environmental risk assessments could be adapted to the practice of LCA."

These issues have been subsequently discussed in further detail in publications such as the Nordic Guidelines on Life-Cycle Assessment (1995), and the SETAC Europe publication, Towards a Methodology for Life-Cycle Impact Assessment (1996). The relationship between LCI and environmental mechanisms has also been a point of considerable discussion within the ISO Life-Cycle Impact Assessment working group (ISO SC5/WG4).

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[2] For a further description of complex networks, refer to the 1996 SETAC Europe publication, *Towards a Methodology for Life-Cycle Impact Assessment*, ed. by H.A. Udo de Haes, Centre of Environmental Science (CML) Leiden University, p. 20.

3. A Proposed Technical Framework for Life-Cycle Impact Assessment

The two key components to any framework for life-cycle impact assessment are: 1) that the assessment boundaries must be extended into the affected environment; and 2) that there must be an ability to mechanistically link system inputs and outputs to actual environmental effects. The "life-cycle stressor-effects assessment" framework (LCSEA) described in the remainder of this document is built upon these principles.

LCSEA was developed specifically to calculate the global, regional and local impact indicator (or sub-indicator) values representing the stressor-effect networks (i.e., environmental mechanisms) relevant to the system studied. In addition, by including threshold levels, the LCSEA calculations can show where there are no measurable indicator values (NMIV) even when corresponding input/output values exist, and thus streamline the analysis.

Because LCSEA seeks to represent the linkages between systems and their effects, quantification focuses on impact indicators (and sub-indicators) that reflect not only the input/output values but also the magnitude, duration and size of the corresponding actual effects on the environment.

Environmental mechanisms are generally recognized to include effects on ecosystems, effects on human health, and the rate of depletion or accretion of natural resources. Under the LCSEA framework, the impact indicators representing these mechanisms are divided under two headings which correspond to the input/output data structure — Net Resources Depleted/Accreted (corresponding to inputs) and Emission Loadings (corresponding to outputs). (See Table 1.)

LCSEA's expanded assessment capability is accomplished by:

- maintaining inventory data in a disaggregated form;
- incorporating data from the "providing" environments (i.e., the source of material inputs) and data from the "receiving" environments (i.e., the repository for emission outputs); and
- modeling the environmental mechanism through defined stressor-effects networks

Table 1 — LCSEA Impact Indicators[3]

NET RESOURCES DEPLETED	EMISSION LOADINGS
Water	Air Greenhouse Gases [c]
Wood	Acidification
Fossil Fuels	Ground Level Ozone
Non-Fuel Oil and Gas	Stratospheric Ozone Depleting Substances [d]
Metals (specific)	Trace Hazardous Chemicals (Air) [e]
Minerals (specific)	- PM 2.5-10 (respiratory pulmonary)
Marine	- <PM 2.5 (respiratory pulmonary)
Land Area	- Aromatics TRI (oncogenic)
- Terrestrial Habitat	- Heavy Metals TRI (oncogenic)
- Aquatic Habitat	Noise
- Aquatic Habitat	
- Soil [b]	Water: Eutrophying Chemicals
	Total Organic Carbon (TOC) / BOD

[3] Additional indicators and sub-indicators may be identified. For example, in addition to receiving environment impacts associated with air and water emissions, some emissions may result in impacts through direct mechanistic pathways, as in the case of chemical residues in food. Direct impacts from microbiological contaminants might also require a separate indicator.

NET RESOURCES ACCRETED	Total Suspended Solids (TSS)
Water	Trace Hazardous Chemicals (Water) [/f]
Wood	- Heavy Metals TRI (acute ecotoxicity)
Marine	- Non-metals TRI (acute ecotoxicity)
Land Area	Thermal
- Terrestrial Habitat	
- Wetland Habitat	Non-treatable Hazardous Waste [/g]
- Aquatic Habitat	
- Soil	

[/a] as defined by the U.S. Department of Interior

[/b] refers to depletion (accretion) of the soil itself, not the habitats or biodiversity supported by the soil

[/c] as defined by the Intergovernmental Panel on Climate Change (IPCC)

[/d] as defined under the Montreal Protocol

[/e] as defined under the U.S. Clean Air Act

[/f] as defined under the U.S. Clean Water Act

[/g] includes both post-treatment and non-treatment wastes

Within this enlarged framework, it becomes possible to characterize the stressor-effects networks with the appropriate spatial, temporal, dose-response and threshold resolutions. This characterization represents the most significant departure from the mass and energy framework.

Figure 4 presents a framework schematic of the assessment process and the specific steps involved in conducting a LCSEA study.

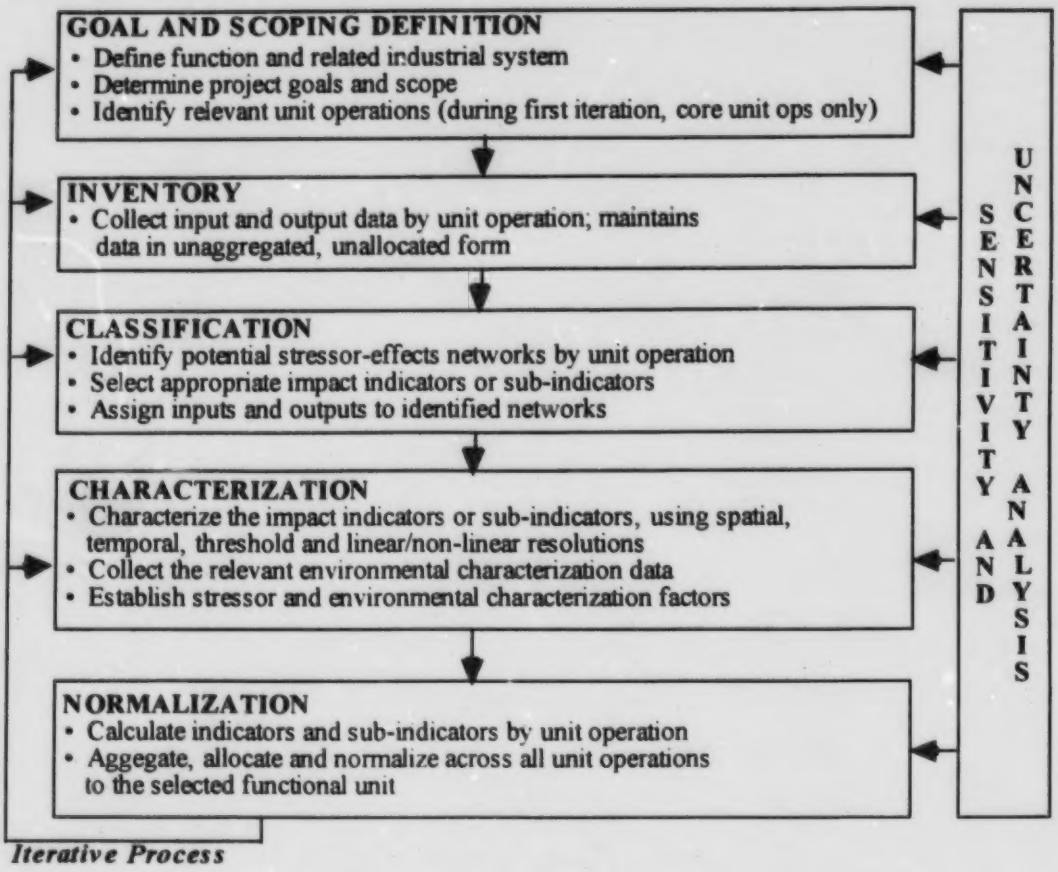
GOAL AND SCOPING DEFINITION
• Define function and related industrial system
• Determine project goals and scope
• Identify relevant unit operations (during first iteration, core unit ops only)
INVENTORY
• Collect input and output data by unit operation; maintains data in unaggregated, unallocated form
CLASSIFICATION
• Identify potential stressor-effects networks by unit operation
• Select appropriate impact indicators or sub-indicators
• Assign inputs and outputs to identified networks
CHARACTERIZATION
• Characterize the impact indicators or sub-indicators, using spatial, temporal, threshold and linear/non-linear resolutions
• Collect the relevant environmental characterization data
• Establish stressor and environmental characterization factors
NORMALIZATION
• Calculate indicators and sub-indicators by unit operation
• Aggegate, allocate and normalize across all unit operations to the selected functional unit
SENSITIVITY AND UNCERTAINTY ANALYSIS
Iterative Process

Figure 4 — Basic LCSEA Process

4. Key Features

4.1. Retains Basic LCA Features

The LCSEA framework retains the essential dynamics and features of basic LCA. For example:

- The framework is iterative, and involves the same basic steps — 1) goal and scope definition, 2) acquisition of system input/output data, and 3) impact assessment with classification and characterization procedures.
- The linked unit operations comprising the system being studied— i.e., the individual process or set of processes which together produce a discrete product, service, or activity — remain the central focus of the assessment.
- The assessment produces quantitative values that are calculated for each unit operation, then normalized to a defined functional unit.

- **Techniques of analysis, including sensitivity and uncertainty analysis, are used to structure data collection and analysis, and to determine the level of confidence in the study findings.**

4.2. Functional Unit

Under the mass/energy LCA framework, the inventory analysis is concerned with establishing the extended mass and energy flows of a system. The selection of the functional unit is not linked to the order of scale of actual production or product use. Rather, any functional unit can be selected, provided that it is a unit that can be used to normalize the results of the mass and energy balance. In the case of washing machines, for instance, it would not matter whether the functional unit is the washing capacity of a single machine over one year, or a million machines over their expected lifetime use, since one would simply be considered a multiple of the other.

LCSEA, by contrast, is anchored in time and space, and is focused upon the calculation of impact indicator values. As such, the functional unit must reflect the actual unit operations located at specific locations during a specified time period, and the associated scale of production and product use. In other words, in order to conduct impact assessment, the functional unit must have a consistent spatial and temporal scale to the processes that are linked to actual effects in the environment. For example, in the case of clothes washing machines, the functional unit should reflect the total number of wash cycles from all machines in a geographic region over a specified period of time.

4.3. Impact Indicator Database

Rather than producing a data set consisting of the cumulative, normalized inputs and outputs of an industrial system, the LCSEA framework generates a set of impact indicator values that represent and correspond to each of the global, regional and local stressor-effects networks relevant to the system being studied. This is a fundamental distinction between the LCSEA framework and its mass and energy counterpart.

The exercise involves the identification and subsequent quantification of impact indicator and sub-indicator values that can characterize the magnitude, duration and scale of the cumulative effects resulting from the industrial system being studied. From a stressor-effects perspective, the indicator or sub-indicator used is that which can best characterize the environmental impact (i.e., endpoint effect) in the providing or receiving environment caused by the system being studied.

It is critical that the indicators or sub-indicators chosen have clear linkages to the magnitude, duration and size of the effect. Once the appropriate indicator or sub-indicator is identified, a mathematical algorithm is developed to reflect the relationship between the stressor, the indicator and the corresponding endpoint effect(s). Included in these algorithms is a set of characterization factors, as discussed below.

4.4. Characterization Factors

In order to quantify the impact indicator and sub-indicator values, characterization (equivalency) factors must be established. These characterization factors incorporate both the relative potency of the inventory values being aggregated, and the general magnitude, size and duration of identified effects on the environment. The process of establishing and applying these characterization factors is critical in developing the algorithms which describe the environmental mechanisms and which are used to calculate indicator values.

The two general types of characterization factors are:

- **Stressor characterization factors** — used to aggregate inputs/outputs into common equivalent units based on their relative physical, chemical or biological potencies with respect to the environment for a given impact category (e.g., CO_2 equivalents, total molar acid equivalents).

- **Environmental characterization factors** — used to reflect the relative severity of a given environmental effect in the relevant "providing" or "receiving" environments, based upon the magnitude, spatial scale and duration of the effects in a given stressor-effects network.

Both the characterization factors and the algorithms are derived empirically from environmental data (see discussion below).

4.5. Calculating Indicator Values

The calculation of indicator values is consistent with the cumulative nature of LCA.

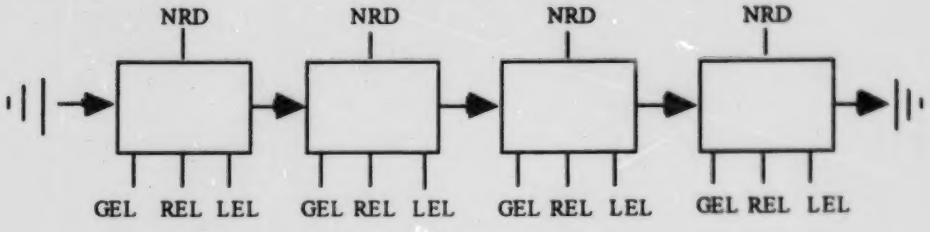

Figure 5 — Linking unit operations under LCSEA[4]

The calculation of the indicator values is expressed by the following equation:

for each unit operation:

$$\text{Indicator Value } (IV_i) = \text{Stressor Value [SV]} \times \text{Stressor Char. Factor [SCF]} \times \text{Environmental Char. Factor [ECF]}$$

$$\text{Cumulative Indicator Value} = \sum_{i=1}^{n} IV_i \text{ across unit operations (n)}$$

The indicator value is the product of the stressor value and the stressor and environmental characterization factors. The cumulative indicator value is the sum of indicator values aggregated for all unit operations.

The use of stressor and environmental characterization factors, and the calculation of indicator values, is illustrated for the acidification stressor-effect network in Table 2.

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[4] NRD= Net Resource Depletion, GEL = Global Emission Loading, REL = Regional Emission Loading, LEL = Local Emission Loading

Unit Operation	Inventory Emission	LCI Value (ton/30a)	Stressor Character-ization Factor	Total Molar Acid Equiv.	Environ-mental Character-ization Factor	LCSEA Emission Loading (ton/30a)
Coal mining/ transport	SOx	31,620	1.00	31,620	0.5	15,810
	NOx	9,660	0.70	6,762	0.3	2,029
	HCl	270	0.88	238	0.5	119
CaO product/ transport	SOx	240	1.00	240	0.15	36
	NOx	1,260	0.70	882	0.075	66
Coal use	SOx	50,190	1.00	50,190	0.15	7,529
	NOx	36,480	0.70	25,536	0.075	1,915
	HCl	15,210	0.88	13,385	0.15	2,008
Total				**128,853**		**29,512**

Table 2 —
Calculating the cumulative acidification loading

As illustrated above, the use of stressor characterization factors only (i.e., total molar acid equivalencies) would lead to a worst-case loading of 128,853 tons, while the incorporation of the environmental characterization factors reduces the reported loading value by more than four-fold to 29,512 tons, reflecting only that fraction which actually contributes to acidification.

One of the challenges in calculating indicator values is that a given stressor may be involved in multiple stressor-effects networks. The potential for double accounting of inputs or outputs is minimized in two ways:

1) Identification of the locality of each unit operation and the magnitude, duration and size of effects makes it possible to eliminate indicator calculations for networks that are inactive.

2) Characterization of the receiving environment makes it possible to determine the relative contribution of a given stressor to active parallel or serial stressor-effects networks.

4.6. Aggregation and Allocation Procedures

Under the LCSEA framework, the calculation of net resource depletion and emission loadings requires that input/output data be kept firmly linked to individual unit operations, and that the order of scale of these data be maintained. Instead of aggregating inputs and outputs on a mass basis as a part of the inventory analysis, data are aggregated and allocated only after the appropriate characterization factors have been established and applied (Fig. 6). It is the indicator values of each unit operation, rather than the raw input/output data, that are then aggregated across unit operation boundaries.

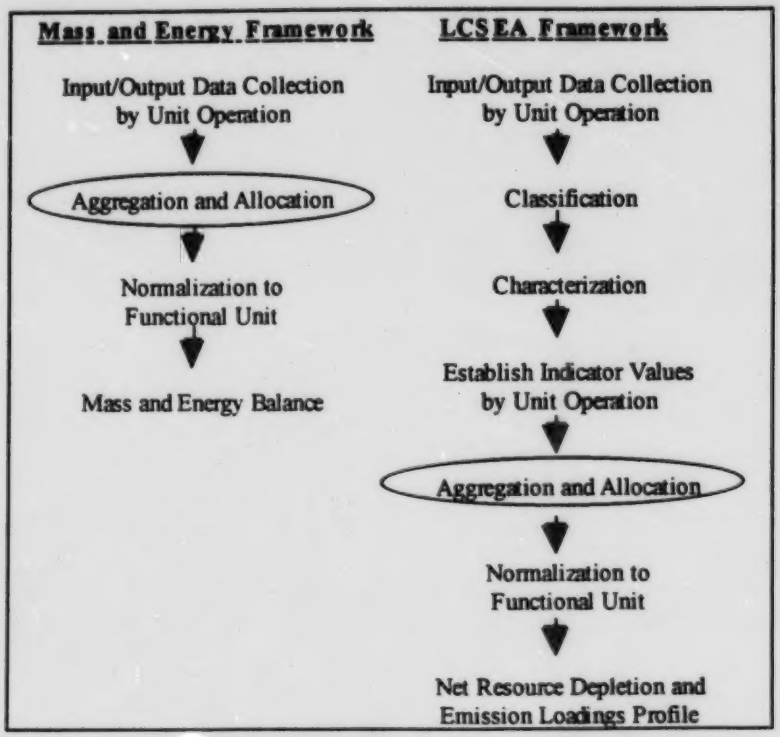

Figure 6 — Aggregation and Allocation under LCSEA Framework

Embedded within current mass and energy LCI models are output values which are actually gross aggregations of many compounds. For instance, AOX (absorbable organic halides) values are generally aggregated under one sum total, even though this class of chlorinated hydrocarbons consists of up to 10,000 different chemical compounds representing a spectrum of impacts and half-lives in the environment. As shown in the example in Table 3, the initial discharge values of AOX are radically different than the bioaccumulative fraction.

Table 3 — Comparing Total AOX values to Total EOX values in Kraft Pulp Bleaching Effluent

Type of bleaching	Typical AOX values for kraft pulp bleaching effluent	EOX values for softwood kraft pulp bleaching effluent *(bioaccumulative fraction)*
Conventional[5]	3.7 - 6.8 kg/t	0.008 - 0.07 kg/t
Elemental Chorine Free (ECF)	0.9 - 1.7 kg/t	0.0009 - 0.01 kg/t

[5] Conventional is defined here as chlorine bleaching processes with up to 10% chlorine dioxide substitution (Dence, Reeve, 1996)

4.7. New Environmental Data Collection Requirements

In order to establish the appropriate characterization factors, the LCSEA framework provides formal procedures for expanding data collection beyond the unaggregated, unallocated input/output data to include environmental characterization data more commonly obtained under other environmental assessment techniques, such as Risk Assessment (RA) and Environmental Impact Assessment (EIA), or derived from other local and regional data sources (e.g., government statistics).

Examples of the environmental characterization data collected include:

- local/regional exposure data;
- background concentration levels;
- exceedence of threshold levels by GIS mapping for acidification and ground level ozone formation;
- size of reserve base for a given resource;
- recycling rates for a given material, and number of times recycled;
- composition and structure of floral and faunal types.

4.8. The Iterative Process

LCSEA's transition into an indicator data system has important implications for the practical application of the framework to the study of industrial systems. As stated above, sensitivity and uncertainty analysis are applied on an iterative basis to structure data collection and determine the significance of results. These techniques are critical to the streamlining of the data collection and analysis, and make possible a sharp contrast with traditional mass and energy data collection and processing. Under the mass and energy framework, it has been estimated, for instance, that some 98% of the unit operation data must be collected in order to achieve a 95% level of confidence that all of the environmentally significant data have been included. (Franklin, 1997)

During the first LCSEA iteration (that is, the first round of assessment), the core unit operations of the system are identified. (Core unit operations are those operations which contribute most significantly to the material basis of the system.) From these data, it is possible to establish preliminary calculations of the net resources depleted and emissions loadings.

Once the first iteration is completed, secondary unit operation data can then be examined. Sensitivity analysis is used to measure the potential significance of an input/output from a secondary unit operation against the cumulative loading for a given indicator. This analysis determines the extent to which additional data collection and analysis are required. It also indicates when there is no justification for further data collection from a given unit operation — that is, when the inputs/outputs of a given unit operation would not significantly affect any of the indicator values.

4.9. Units of Measure

The units of measure reported for the indicators under each of these categories are not mass units, as in the case of mass and energy LCI study findings. Rather, the units of measure express the unique equivalencies used to calculate each indicator (Tables 4a and 4b).

Net Resources Depleted / Accreted

For net resources depleted (or accreted), the units of measure express the effective equivalent depletion (or accretion) of the identified resource. All of the net resource calculations are

based on the reserve base depletion factors (RBDF), as discussed in the LCSEA Practitioner's Manual.

Table 4.a — Indicators for Net Resources Depleted/Accreted with Corresponding Units of Measure

INDICATOR	UNITS OF MEASURE
NET RESOURCES DEPLETED	Amount depleted expressed in:
Water	equivalent cu.m.
Wood	equivalent cu.m.
Fossil Fuels	tons of oil equivalents
Non-Fuel Oil and Gas	tons of oil equivalents
Metals (specific)	tons of (specific metal) equivalents
Minerals (specific)	tons of (specific mineral) equivalents
Marine	TBD
Land Area	
- Terrestrial Habitat	equivalent hectares
- Wetland Habitat	equivalent hectares
- Aquatic Habitat	equivalent hectares
- Soil	equivalent hectares
NET RESOURCES ACCRETED	Amount accreted expressed in:
Water	equivalent cu.m.
Wood	equivalent cu.m.
Marine	TBD
Land Area	
- Terrestrial Habitat	equivalent hectares
- Wetland Habitat	equivalent hectares
- Aquatic Habitat	equivalent hectares
- Soil	equivalent hectares

Equivalent Emission Loadings

For emissions, the units of measure express equivalent loadings, based on the application of appropriate stressor and environmental characterization factor.

Table 4.b — Indicators for Emissions Loadings with Corresponding Units of Measure

INDICATOR	UNITS OF MEASURE
EMISSION LOADINGS	Amount loaded expressed in:
Greenhouse Gases	tons of CO_2 equivalents
Acidification	tons of SO_2 equivalents
Ground Level Ozone	tons of O_3 equivalents
Stratospheric Ozone Depleting Substances	tons of CFC-11 equivalents
Trace Hazardous Chemical (Air)	
- PM 2.5-10 (respiratory/pulmonary)	equivalent tons
- <PM 2.5 (respiratory/pulmonary)	equivalent tons
- Aromatics TRI (oncogenic)	equivalent tons
- Heavy Metals TRI (oncogenic)	equivalent tons
Noise	decibels
Eutrophying Chemicals	tons of PO_4 equivalents
Total Organic Carbon (TOC) / or BOD	tons of oxidizable C equivalents
Total Suspended Solids (TSS)	TBD
Trace Hazardous Chemical (Water)	
- Heavy Metals TRI (acute ecotoxicity)	equivalent tons
- Non-metals TRI (acute ecotoxicity)	equivalent tons
Thermal	equivalent BTUs
Non-treatable Hazardous Waste	equivalent tons

4.10. Establishing Levels of Confidence

In the mass and energy framework, uncertainty analysis is concerned with determining the degree of confidence in the input/output values reported. Under the LCSEA framework, uncertainty analysis goes a step further by measuring the degree of confidence in the descriptions of the environmental mechanisms themselves, and in the relationships between inputs/outputs and endpoint effects. Determining this level of uncertainty is critical, given that the indicator loadings themselves are based on measures of specific impact indicators along the stressor-effect networks, and generally not on measures of actual endpoint effects.

Once the uncertainty of the indicator values for each specific unit operation is determined, it is then possible to calculate the uncertainty for each cumulative indicator value for the overall system.

5. Methodology Applications

The impact indicator values calculated under LCSEA essentially summarize the active stressor-effects networks triggered in whole or in part by the industrial activity studied. As such, the

LCSEA framework can support a variety of applications beyond those traditionally associated with LCA: 1) to serve as a basis for corporate Environment Performance Evaluation (EPE); 2) to support environmental improvement decision-making and supply chain objectives; and 3) to create an objective basis for Type III eco-labelling and resulting claims of environmental achievement, including Certified Environmental State-of-the-Art, Certified Environmental Improvements, and Certified Environmental Advantages.

The cradle-to-grave breadth of LCA, combined with the fact that impact indicator values are calculated for each unit operation, provides the necessary foundation for strategic environment planning, design and improvement. Improvement strategies can be precisely targeted to address the first tier of impacts associated with each unit operation.

However, while this level of information represents an important milestone, it stops short of representing a measure of sustainability. The following section describes some of the key issues and obstacles that would have to be addressed before the sustainability of an industrial system could be established.

6. Issues in Assessing Sustainability

6.1. The Spatial and Temporal Nature of Sustainability

While LCSEA currently produces a set of impact indicator values which represent the environmental mechanisms set into motion by the industrial activity, these indicators may be considered stepping stones toward the eventual assessment of sustainability.

The question of sustainability is both a spatial and a temporal one, whereby a given area and specified timeframe must be established in order to determine whether the current activity can be sustained against an acceptable baseline, given the current and future environmental conditions and stresses. The ability to quantify sustainability thus hinges on: 1) the ability to determine an appropriate timeframe within which to assess sustainability; 2) the ability to define the appropriate geographic boundaries; 3) the ability to establish appropriate baseline conditions against which to measure changes; and 4) the ability to project environmental conditions into the designated time horizon in order to establish the appropriate environmental characterization factors.

Each of these hurdles is significant. For instance, the timeframe chosen for the assessment could dramatically alter the results of a study. Whether sustainability is measured in the context of current industrial activity (e.g., projected out over a period of 50 or 100 years), or in the context of future generations (e.g., 150 years, 200 years, or more) is a key assumption for the study, and could be a key variable. Clearly, the longer the period of assessment, the greater the measure of true sustainability. At the same time, the further the assessment projects into the future, the greater the uncertainty of results, given the array of anticipated and unanticipated factors which can affect environmental conditions.

6.2. The Need to Include All Relevant Impacts

A common tendency among policy makers and other decision makers in identifying sustainable development options is to focus on certain indicators, while excluding others. However, this approach can lead to a situation in which significant environmental trade-offs are overlooked.

Under the LCSEA technical framework, all systems are examined in terms of a core set of impact indicators to ensure that such trade-offs are apparent (Table 1 above). Any scientific assessment of sustainability must encompass these indicators.

The following discussion provides examples of some of the challenges in calculating sustainability.

a. "Sustainability of Resources"

Currently, the time horizon for calculating the rates of depletion of resources is generally limited to about 50 years, based on the availability of reliable data with a reasonable degree of certainty. Extension of this time horizon may be critical in determining the degree of "sustainability" of a given resource, but could be difficult to achieve, depending on the impact in question.

- ***Sustainability of Water Resources.***

  Based on a 50-year outlook, many fresh water reserve bases are undergoing a severe rate of net depletion. However, the long-term environmental significance of this current depletion is highly uncertain. For example, one of the projected consequences of global warming is an overall increase in water vapor, leading to subsequent increases in rainfall in certain regions. Adding to the uncertainty, it is not clear whether such additional precipitation would necessarily translate into increased fresh water reserve bases. For example, increased rainfall might do little to restore underground aquifers if the intensity of the storm systems causes most of the water to run off as flash floods, or if land uses rendered the ground impermeable.

- ***Sustainability of Wood Resources.***

  Millions of acres of natural forestlands in South America and Southeast Asia are currently being cleared for fuel, agriculture, tree farming, urban expansion, and other uses. While many of these practices are resulting in a net depletion of timber resources, this is not always the case. For instance, tree farming can be more productive in terms of timber resources than natural forests. However, if clearing forests results in loss of soil productivity, then such production increases would likely be short-lived, resulting in greater net depletion over the long term. Another potentially negative trend for wood reserve bases is related to global climate changes, which can affect the regional boundaries within which selected species thrive. At the same time, such losses might be potentially offset, at least in part, by modern industrial forestry techniques. Given these variables, the uncertainties surrounding wood resources would appear to be too great at present to determine the degree of sustainability.

  Sustainability of Marine Resources.

  Most of the major fisheries in the world are either at maximum harvest capacity or are severely depleted. It has been suggested that aquaculture can help restore wild populations to sustainable levels. While this may be true, it is also frequently the case that aquaculture uses brood stock from wild populations, a practice which can itself put a strain on such populations. In addition, aquaculture typically uses other species of fish as feedstock; as a result, the feedstock fish are sometimes severely depleted to support the commercial species. Currently, there is no methodology for calculating impact indicator values, let alone calculating the degree of sustainability.

- ***Sustainability of Steel, Aluminum and Other Selected Metal and Mineral Resources.***

  Within the current LCSEA framework, the reserve base is defined as that portion of an identified resource that meets the minimum chemical and physical characteristics required to meet current mining and production practices. This definition is consistent with definitions

proposed by Heijungs et. al. (1992), and by the US Bureau of Mines (1993), which defines economic reserves as including both the portion of ground reserve bases which can be economically extracted at a given time, and also the degree to which the technologies exist to reuse or recycle the standing stock of these resources. Many metal and mineral resource impact indicator calculations are projected to have low rates of depletion over time horizons of 100-200 years, given current reserve bases and recycling technologies. These time horizons may well be sufficient for calculating the degree of sustainability.

Another factor working in favor of long-term sustainability is the fact that as technology advances continue to enhance material properties, the amount of material required to perform specific functions has been substantially reduced. As such, the rate of depletion of reserves to perform these functions could be slowed down. For example, new alloys of steel can be used to substantially reduce the amount of steel used in automobiles.

- ***Sustainability of Fossil Fuels.***

Unlike metals and minerals, which retain their material integrity and can be reused, fossil fuel resources are used in a consumptive manner (i.e., burned as fuel), such that sustainability is purely a reflection of the size of reserve bases and the rate of use. There is currently a widespread perception that fossil fuel resources are rapidly being depleted and are unsustainable. However, this perception depends on the time horizon identified. Indeed, the proven and potential reserve bases of these resources have been only partially characterized. New reserves are being discovered, as in the case of the natural gas reserves in Eastern Russia, which are estimated to be larger than the entire middle eastern oil reserves. Natural gas trapped in seabeds is also considered to be a significant potential reserve base for future exploitation. Coal reserves are already measured in the hundreds of years. On the other hand, oil reserves appear to have a distinctly limited reserve base of less than 50 years.

- ***Sustainability of Ecosystems.***

As described earlier, four sub-indicators (terrestrial habitat, wetland habitat, aquatic habitat, and soil) have been identified to stand as surrogates for the impacts of industrial systems on ecosystems as a result of the direct use of land. From a sustainability standpoint, some limited calculations could be derived, depending on the temporal and spatial assumptions applied. For example, within a relatively short time-span (e.g., under 50 years), it can be assumed with reasonable certainty that impacts from certain industrial land uses (e.g., road building, urbanization) will not be reversible. Over a longer time horizon, some recovery might indeed take place, depending on future environmental, social and economic conditions; however, the uncertainty attending such circumstances would be quite high. The use of a 50-year time-frame may be appropriate, in any case, given current predictions that more than half of the species existing today will become extinct over the next 50 years.

b. The Relationship Between Emission Loadings and Sustainability

- ***Greenhouse Gas Loading.***

This indicator can be temporally characterized to fulfill some of the basic requirements for calculating sustainability. The rise in background concentrations of various greenhouse gases, based on current and projected industrial practices, is fairly well established, along with the projected increases in global temperatures. For example, over the next 100 years, given current trends, the background concentrations for CO_2 are projected to rise to 750 ppm; at this concentration, global temperature models indicate that the north pole could

increase in temperature by 24° F, with overall global temperatures rising by over 6-10° F. However, the calculation of sustainability is hampered by the uncertainties surrounding the corresponding endpoint effects, and the diversity of such effects (e.g., crop failures, declines in species, rising oceans and resulting losses in land area, etc.). It is still not clear, for instance, what types of environmental characterization data are required to measure these endpoint effects.

- ***Stratospheric Ozone Depleting Substance Loading.***

  As in the case of global warming calculations, this indicator can be temporally characterized to fulfill some of the basic requirements for determining the degree of sustainability. The relative potencies of various chemicals are well established, and the atmospheric retention is reasonably well understood. Again, however, in order to calculate sustainability, considerable assumptions would be required as to the overall background concentrations of ODS's in the atmosphere over time, given the degree of compliance with international treaties, the rate of illegal usage of ODS's, and the pace of technology developments which could make the use of such chemicals obsolete.

- ***Hazardous Chemical Loadings.***

  The establishment of impact indicators for chemical releases classified as hazardous is still in its infancy. Many indicators cannot currently be calculated, due to the high uncertainty in relating system stressors to actual human health or eco-toxic effects. As such, attempting to determine the degree of sustainability in terms of human health or eco toxicity would not appear to be feasible today.

6.3 The Need to Proceed with Conceptual Discussions Regarding the Calculation of Sustainability

The evolution of life-cycle assessment from mass and energy balances to impact assessment, and eventually, to the assessment of sustainability, is a logical progression reflecting the need for reliable, reproducible data about the impacts of human industrial and commercial activities. As this paper has attempted to illustrate, the state of the science is only now emerging to the point where a technical framework for life-cycle impact assessment can be put into practice.

Although significant hurdles must be overcome, conceptual discussions about the measurement of sustainability should proceed now. Such discussions are timely, in light of two basic facts: 1) the depletion of resources, degradation of air and water quality, and destruction of habitats are matters of increasing concern that will continue to grow in the coming decades; and 2) pressures to address these concerns will likewise increase, leading to a demand for appropriate assessment tools.

It can be anticipated that such discussions will be facilitated by the current impact assessment practice and its results, which will undoubtedly help to shed new light on the issues involved in quantifying sustainability. As such, the findings of assessments conducted under the LCSEA and other impact assessment frameworks should be closely monitored.

Eco-Indicators for Products and Materials: State-of-Play '97
Toronto — November 25, 1997

Life-Cycle Stressor-Effects Assessment

A Framework for Developing Quantitative Eco-Indicators

Linda G. Brown
Scientific Certification Systems, Inc.

Establishing Eco-Indicators

How does this product/system impact the environment?

How "sustainable" is this activity?

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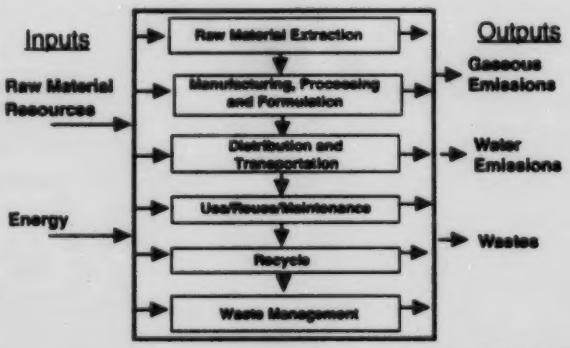
Standard LCA Practice: Life-cycle inventory



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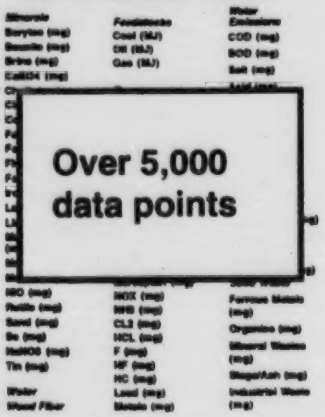
INPUT/OUTPUT DATA



Life-Cycle Inventory

✔ **Excellent tool for tracking material and energy flows in industrial systems . . .**

- **Cradle-to-grave scope**
- **Consistent data requirements across different industry sectors**

X **Not designed to support the establishment of eco-indicators.**

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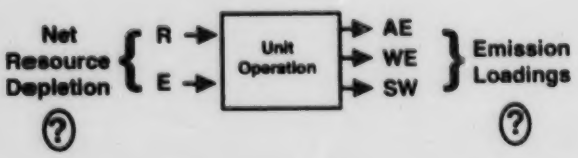
1. Analysis is confined to physical perimeters of the system's unit operations.



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2. Aggregation and allocation procedures eliminate the spatial and temporal information needed to link input and output data to actual effects.

Raw material extraction	NOx
Shipping	NOx
Manufacturing	NOx
Use	NOx
	Σ NOx

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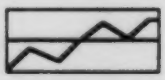
3. The functional unit does not account for the size or scale of production at the various unit operations, nor take the location of these operations into account.

Functional Unit:
1 widget □

Production: small or large?

Receiving environment: emissions below threshold or above threshold?



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4. Only elementary flows are analyzed, precluding the ability to address impacts associated with an industrial system's land use — impacts on biodiversity and habitats.

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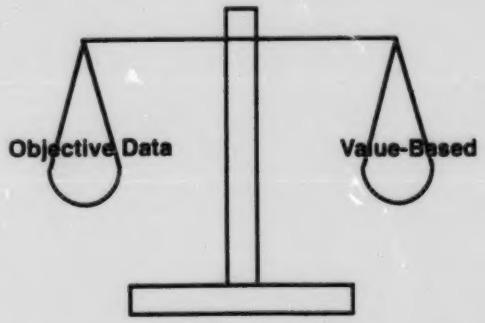
Historic Eco-Indicator Approaches



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Using inver as indicators —
leads to s better" judgements

Less is not always better

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Weighting, ra d sc chemes —
Using value portance of
different t

- Precau
- Recy

Easy to overlook trade-offs

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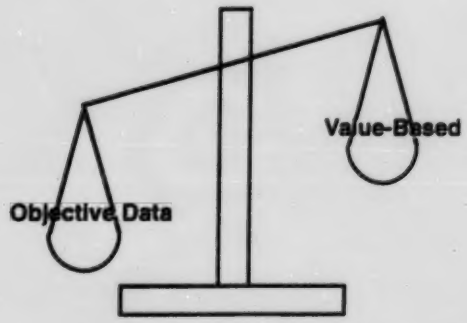
Evolution in Eco-Indicators



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Basic Requirements for Eco-Indicators

- Represent impacts from cradle-to-grave
- Quantitative - represent actual magnitude and duration of impacts
- Uniform framework of assessment
- Transparent assumptions and defined uncertainty
- Practical

→ LCA ?

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An LCA Framework Designed for Developing Quantitative Impact Indicators:

Life-Cycle Stressor-Effects Assessment

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LCSEA Development

Countries (examples)

- Sweden
- Finland
- US
- Japan

Industries (examples)

- Basic Material Industries (Steel, Wood)
- Energy Industry (Natural Gas, Hydro, Coal)
- Consumer products (Appliances)
- Electronic Products (Mobile-Fixed Phone System)

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Key Features of LCSEA Technical Framework

- Extends assessment to include the affected environment.
- Provides formal framework for integration of data from other environmental assessment tools (e.g., EIA, RA).
- Allows for calculation of global, regional and local impact indicator values relevant to the system.
- Calculates quantitative impact indicator values based upon actual environmental mechanisms.
- Addresses impacts with no corresponding LCI inventory values (i.e., Net Land Area Depletion).
- Does not include weighting, scoring or aggregation across environmental mechanisms.

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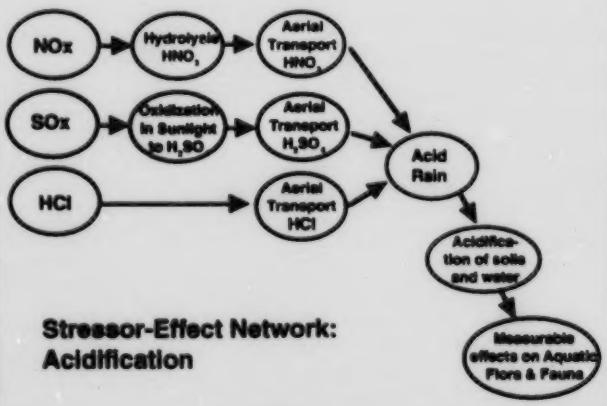

Stressor-Effect Network: Acidification

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Impact Indicators

Indicators (and sub-indicators) divided under two general headings to correspond with the input/output data structure of LCA:

Net Resources Depleted
corresponds with inputs

Emission Loadings
corresponds with outputs

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Net Resource Depletion Impact Indicators

Net Water Resources Depleted	Gain
Net Wood Resources Depleted	Gain
Fossil Fuels Depleted	
Net Non-Fuel Oil & Gas Depleted	
Net Mineral Resource Depleted (specific)	
Net Metal Resource Depleted (specific)	
Net Marine Resource Depleted (specific)	Gain
Net Land Area Depleted (due to direct physical or mechanical disturbance)	Gain

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The Identification of Sub-Indicators

Net Land Area Depleted →

- Net terrestrial habitat depleted
- Net wetland habitat depleted
- Net aquatic habitat depleted
- Net soil depleted

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Emission Loadings
(Route of exposure — Air)

- Greenhouse Gases
- Acidification
- Ground Level Ozone
- Stratospheric Ozone Depleting Substances
- Trace Hazardous Chemicals Sub-Indicators
  (examples by specific mechanism)
  - PM 10 (respiratory/pulmonary)
  - Heavy Metals - TRI (oncogenic)
  - Aromatics TRI (oncogenic)
- Noise

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Emission Loadings
(Route of exposure — Water, Ground)

- Eutrophying Chemicals
- Total Oxidizable Organic Carbon (TOOC)
- Total Suspended Solids (TSS)
- Trace Hazardous Chemical Sub-Indicators
  (examples by specific mechanism)
  - Heavy Metals - TRI (oncogenic)
- Non-Treated Hazardous Waste (RCRA)

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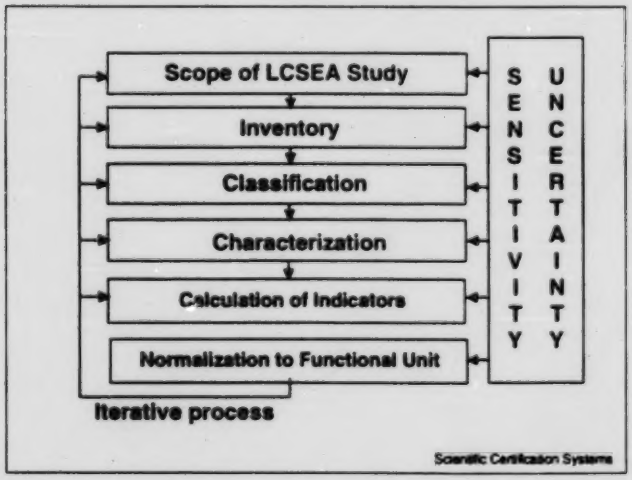

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Core Unit Operations

First iteration of assessment

Focus on core unit operations — those contributing most significantly to the material basis of the system.

Subsequent iterations

Use sensitivity analysis to determine potential significance of net resource depletion or emission loadings from secondary unit operations.

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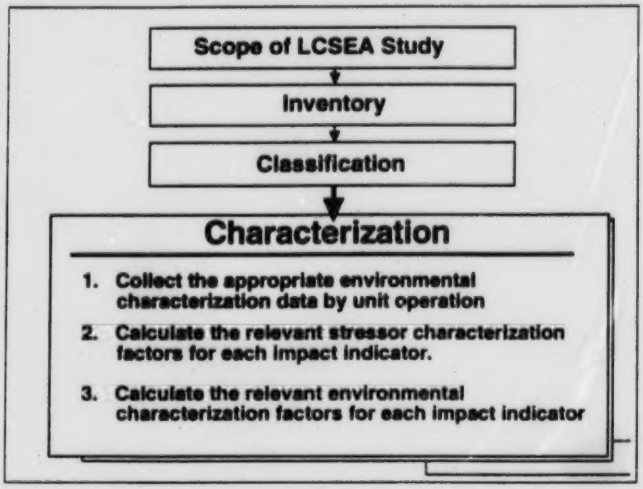
Scope of LCSEA Study
Inventory
Classification
Characterization
1. Collect the appropriate environmental characterization data by unit operation
2. Calculate the relevant stressor characterization factors for each impact indicator.
3. Calculate the relevant environmental characterization factors for each impact indicator

Extending Assessment Boundaries to Include the Affected Environment

Traditional

Stressor Characterization Factors

An equivalency reflecting the relative potency potentials of various stressors active in the same stressor-effect network.

New

Environmental Characterization Factors

An equivalency reflecting threshold levels, the relative magnitude, size and duration of the effects associated with each unit operation.

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Examples of Environmental Characterization Data

For Emission Loading

- Local/regional exposure data
- Background concentration levels
- Regulatory threshold levels

For Net Resource Depletion

- Size of proven, technical and potential resource reserve base
- Recycling rates for specific materials
- Size of "standing stock" reserve base

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Stressor Characterization Factors

Examples (Nordic Guidelines for LCA)

- Global Warming Potentials (GWP)
- Ozone Depletion Potentials (ODP)
- Eutrophication Potentials (EU)
- Photo-Oxidant Chemical Potentials (POCP)
- Acidification Potentials (AP)
- Relative Q* Potentials (RQ*P)

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Environmental Characterization Factor (ECF)

Emissions

1. Does emission exceed threshold?
   - If no, ECF = 0
   - If yes, ECF = 1
2. For ECF = 1, what percentage of emission deposits in areas of exceedance?
3. What is duration and severity of exceedance?

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EMISSION LOADINGS: Route of Exposure - Air

INDICATOR	STRESSOR CHAR. FACTOR	ENVIRON. CHAR. FACTOR (Percentage of total emission above threshold)
Greenhouse Gases	Global Warming Potentials (GWP): 50 years	Threshold level set at 270 ppm. (Exceeded in 1968)
Acidification	Acidification Potentials (AP) (Nordic Guidelines for LCA)	Threshold level set by the Coordination Centre for Effects (CCE) exceedance mapping.
Ground Level Ozone	Photochemical ozone creation potentials (POCP) - Nordic Guidelines for LCA	Threshold level set by CCE at 5500 ppbh. (specific by airshed)
Stratospheric Ozone Depleting Substances	Ozone Depletion Potentials (ODP)	Threshold level exceeded in 1970s.
Noise	TBD - relative frequency potentials?	TBD

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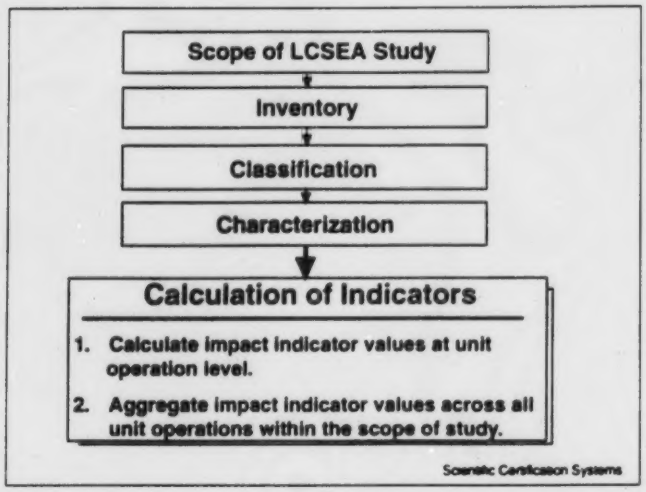
Scope of LCSEA Study
Inventory
Classification
Characterization
Calculation of Indicators
1. Calculate impact indicator values at unit operation level.
2. Aggregate impact indicator values across all unit operations within the scope of study.
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Calculating Indicator Values

For each unit operation . . .

Indicator Value = Inventory Value X Stressor Char. Factor X Environmental Char. Factor

(Indicator VI) = [IV][SCF][ECF]

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Cumulative Indicator Value

For system . . .

$$\text{Cumulative Indicator Value} = \sum_{i=1}^{n} IV_i \quad \text{across unit operations (n)}$$

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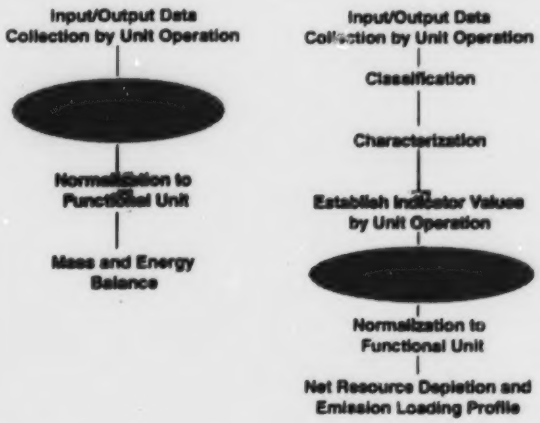
Input/Output Data Collection by Unit Operation
Normalization to Functional Unit
Mass and Energy Balance
Input/Output Data Collection by Unit Operation
Classification
Characterization
Establish Indicator Values by Unit Operation
Normalization to Functional Unit
Net Resource Depletion and Emission Loading Profile

Calculating Emission Loadings

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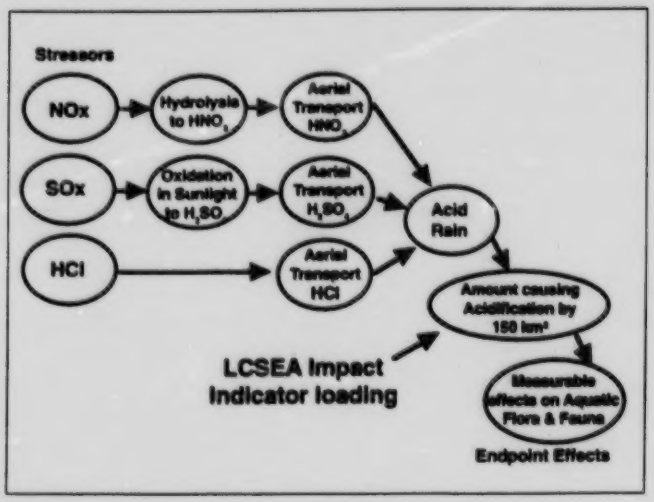

Calculating the Acidification "Emission Loading"

Unit Oper.	Inventory Emission	LCI Value (ton/30a)	Stressor Charact. Factor	Total Molar Acid Eq. (ton/30a)	Environ. Charact. Fact.	LCSEA Emission Loading (ton/30a)
Coal mining / transport	SOx	31630	1.00	31630	0.5	15810
	NOx	9660	0.70	6763	0.3	2029
	HCl	276	0.88	246	0.5	119
CaO product/ transport	SOx	240	1.00	240	0.15	36
	NOx	1360	0.70	952	0.073	66
Coal use	SOx	98198	1.00	98198	0.15	7329
	NOx	36400	0.70	25536	0.073	1915
	HCl	15210	0.88	13385	0.15	2008
				128,853 t		29,512 t

Calculating Net Resource Depletion

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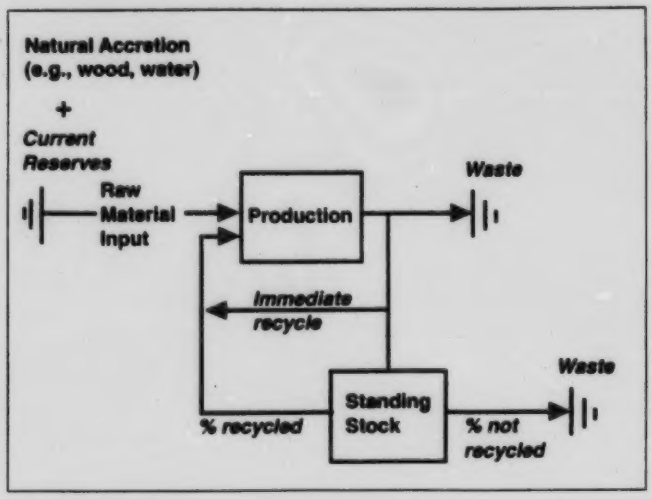

Resource Depletion Factor

$$RDF = \frac{(\Sigma W - N)\,\Delta T + (R_b - R)}{R + (\Sigma S_{mi})\,\Delta T}$$

Scientific Certification Systems

Calculating Net Resource Depletion

Indicator Value (IVi) = Inventory Value [IV] X Resources Depletion Factor (RDF)

IVi = [IV][RDF]

Stressor characterization factor exists only in the case of fossil fuels — tons of oil equivalents

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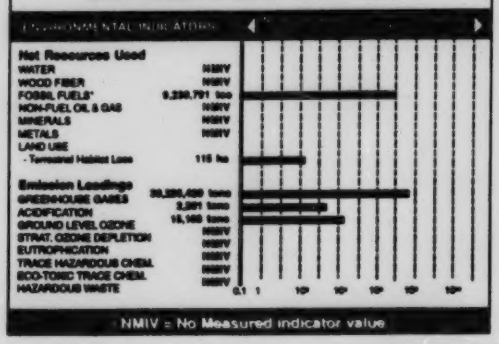
LCSEA ECO-PROFILE

CHP Natural Gas Power Plant



Scientific Certification Systems

Moving Toward Sustainability Indicators

1. **Determine appropriate timeframe**
2. **Define appropriate geographic boundaries**
3. **Establish appropriate baseline**
4. **Ability to project environmental conditions into the designated time horizon.**

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Discussion for Session 1

Chairperson: Steven Young (Demeter Group, Canada)

Nils Larsson (Natural Resources Canada):
How do you get your weighting factor, for CO_2 reduction for example, from the national priority? What were the steps to get you the weighting factor?

Atsuhi Inaba (National Institute for Resources and Environment, Japan):
I used the national policy to reduce CO_2 emissions. The target is 8% reduction in the emissions. The weighting factor is the ratio of the current emission to the target emission.

Justyna Laurie-Lean (The Mining Association of Canada):
To Martin Baitz: What is the meaning of *"worst case estimation needed"* in one of your slides?

Martin Baitz (University of Stuttgart, Germany):
Worst case estimation refers to potential impacts. It is not actual impacts because it is not possible yet to describe the actual fate of emissions during the whole life cycle in the cause-effect-network. Isolation of single known cause-effect chains from the network may lead to heavy misinterpretation of the environmental impacts. Thus, potential impacts must be considered.

Steven Young:
A given molecule can go out and may not specifically make an impact. There is a potential that it would make an impact and this is the worst case.

Martin Baitz:
The impact can happen, but there is no way that we can quantify the rate of several reactions in the atmosphere. The greenhouse potential is a potential, because the emission likely drives the effect, but it is not possible to quantify the chemical fate of every molecule to depict real damage, which leads to potential respectively worst case estimations.

Mark Goedkoop (PRé Consultants, the Netherlands):
It is a very interesting question because we have at the table three perspectives or understanding on damage to the environment:

- University of Stuttgart — Potential impact: worst case
- Scientific Certification System — Real damage to the environment
- PRé Consultants — Potential average damage in Europe

Martin Baitz:
We support the tool-box idea, we think that you cannot measure all impacts of the whole effect network on the whole life cycle within an LCA, but you can point out the hot spots. Special actual situations (e.g. actual toxicity) can be studied with other tools (e.g. risk assessment, substance flow analysis).

Rita Schenck (EcoSense Inc., U.S.A.):
To Mark:
Regarding the issue of using old data, do you have any method to consider new and more precise data from the manufacturer?

Mark Goedkoop:
There are two parts in the eco-indicator methodology. The first is to make LCA more complex by adding weighting factors and weighting steps. The second part is the inventory data used to calculate 100 standard values for frequently used materials and processes. Both parts needed to be updated. We found that the quality of the inventory data was worse than the weighting. The traditional part of LCA is still a problem due to multiple allocations, incompleteness and misunderstanding of the data.

At this point Steven Young introduced the various philosophies used in the development of models or softwares.

Steven Young:

software needs as expressed by the developers:

Mark Goedkoop	"quick tool to analyze and understand for the better or the worst"
Atsuhi Inaba	"something that everyone can use, based on standards"
Jamie Meil	"streamlined as possible, simple as possible"
Martin Baitz	"quick, easy and reliable"

There are differences on how impacts are interpreted and how evaluation is undertaken.

For Mark Goedkoop and Atsuhi Inaba, it is the distance-to-target method. "Target" is the environmental standard that we want to reach. The "distance" is how far away we are from the "target." Jamie Meil's approach is "less is better". From the work at Athena and with a survey of experts, they measure some specific elements for the resource extraction index; benchmarking (similar to distance to target). Martin Baitz's approach is the safeguard subject.

Martin Baitz:
Social panels try to identify the safeguard subject. It cannot be done by environmentalists or engineers only, because the safeguard subjects must be accepted by society. The safeguard subject is the goal we want to reach. So far, it is not possible to link emissions to real environmental effects and, further, to the safeguard subjects. For example, greenhouse gases affect all impact subjects: human health, environmental health and sustainability. When the sea level rises, human beings will die, we will not be able to mine some resources and the ecological systems will be affected. That is the whole network of impacts and just isolating single impact chains is not the correct way. People tried to find out the safeguard subject first in order to bypass the gap between cause and effect. If you

know the goal you may be able to relate those two. There is no consensus of the safeguard subjects so far, as many interdisciplinary themes (ecological, economical, technical, ethical, theological) must be considered.

Steven Young:
At this point in time, you are looking for more flexible weighting and you are imposing that responsibility more on the user or the designer to make that choice in an open and transparent way.
The model from Linda adds an extra level of complexity. Not only are you asking for input and output data but you are also specifically asking for data for localities, regions and global conditions in order to measure the impacts in those environments.

Linda Brown (Scientific Certification System, U.S.A.):
It is not increasing the level of complexity. It is integrating characterization data into the process. The consequence is a simplification and makes some information more straightforward because emission data that have no relation to effects can be set aside during the first iterative assessment. We are interested in prioritizing the information, making it usable and practicable. So you do not try to make decisions based on 200 or 300 data points if you can narrow it down to something useful. The only way we can see to do that is by characterizing the information temporally, specially, in terms of threshold. We are not applying a weighting system across stressors. We do not assign relative importance between global warming vs acidification vs resource depletion. These weighting factors can exist outside the framework as companies may apply them.

Mark Goedkoop:
Linda is making an oranges to apples comparison too. She takes into account detailed background information at site. Martin is not using information about background, and takes the average concentration to determine the average hypothetical damage. We assume that things are happening in Europe and we look at the background concentration in Europe to see if there is extensive damage and to find out where we are on the damage curve. I think we are a little bit in the middle.

Ken Martchek (Alcoa, U.S.A.):
All the methodologies do a good job trying to add up the damages or potential impacts on the environment or human health. None of these methodologies tried to capture the benefits that products provided. As an example, we have a refrigerator: benefits of refrigeration for human health (such as less food poisoning and better nutrition) probably outweigh liability in terms of problems to human health. Is it a place for the benefit side? In business we make a cost benefit analysis. Presently, we seem to be looking on the cost side.

Mark Goedkoop:

It is a very important question. The assumption is that the designer will make the product anyway. It is difficult to see the influence it will have on the environment. Clearly, most of the products are a net benefit for humanity. Otherwise, they would not have been created. In extracting the mineral and producing the refrigerator, you are increasing the concentration of iron and it will be available for recycling in the future. The task of compiling the benefits is very complex. In principle, you are right.

Martin Baitz:
You do not have any information on how people use the refrigerator.

Linda Brown:
It is not only a question of resources depleted but also accreted. This shows that industrial systems have been very responsible toward resources.

J. William Owens (Proctor & Gamble, U.S.A.):
The original purpose of LCI was to gain valuable insights on the material and energy flows and efficiencies throughout a life cycle. Emissions and wastes were intended to reflect this effort to quantify efficiency and to seek improvements. Intervening years have seen effort to use these emission data for impact assessment. However, we have seen difficulties in extrapolating emission loading and resources use in the actual environment. This raises important issues for two groups where:

- producers have to make choices of action to benefit the environment; and
- purchasers have to make choices, not only on cost, but environmental benefits of a purchasing decision.

These groups are faced with important interpretation and communication issues in the use of eco-indicators. When we have a set of emissions that are converted into those indicators: How do we interpret the indicators -- as a loading, or do we try to extrapolate these as 'damages' or effects? We know that they are very imperfect extrapolations. So how do we, in fact can we, derive and interpret the environmental benefits?

How can purchasing agents better define and find out the environmental benefits of their decisions? How do we communicate the actual information of the indicator as an emission loading, not an environmental effect, clear and transparent? This in turn poses an important starting question in this analysis: How do the developers of software models make the assumptions, extrapolations, and value judgements transparent to what are sometimes very naive users?

Jamie Meil (the Athena Institute, Canada):
Cost-benefit analysis. At this point, you can rationalize almost anything. In terms of LCA, we are in a learning curve and not near the diminishing return. With regard to the product manufacturer and efficiency, the Athena Institute talks to producers and they are willing to give to us their data. As a consequence, when the data will be introduced in our model, producers will have the possibility to benchmark their operation to the best practices. Producers are interested in understanding not only by cradle to gate (material extraction)

but also how their product performed in society and in it used form. It can be used in the future by the product manufacturer for pollution prevention or product manufacturing.

Marlo Raynolds (The Pembina Institute, Canada):
PRé and National Agency for Resources and Environment developed eco-indicator systems for countries that are relatively small. How can you make a model for a large country like Canada which has a large number of ecosystems?

Mark Goedkoop:
The whole population of Holland fits into Tokyo, so there is difference of scale. The eco-indicator was developed for Europe. You have to work with averages and you have to simplify to make it easy and manageable. There should be another model for other regions such as North America.

Atsuhi Inaba:
I would like to focus on differences. As the population density is very high in Tokyo and Osaka, these two regions are treated differently from the rest of the country in our model. As an outcome of the model, we do not want to say that we cannot produce a refrigerator in the Tokyo area and that is a problem. My presentation was only a proposal of our indicators. In Japan, we are collecting data for life cycle inventory. We are validating impact from other countries and inviting model developers. A scientific society on LCA was established in Japan three years ago by 200 companies. One of their challenges is the quantification of impact. We have to consider the most important aspects ecosystem and human health. My proposal is to use the national standard or national policy to calibrate the model and to reduce emissions.

Hal Levin (Hal Levin & Associates, U.S.A.):
The use of national standards as targets for establishing "eco-indicators" has been said here to be free of biases and individual value judgments because it is based on risk assessment. This is incorrect. There is an assumption that risk assessment results are "objective" data. I contend that this is not so. There is substantial subjectivity in risk assessment. The methods used to identify the research subjects, to select the research methodologies, and to consider the end points of concern are examples of a large number of judgments reflecting personal and societal biases that pervade a risk assessment process. Then, the risk managers consider factors other than the scientific data -- such as, economic considerations, social justice considerations, and political considerations when setting standards. Therefore, I reject the notion that we can avoid the inclusion of value-based judgments by selecting national standards to calibrate the models.

Atsuhi Inaba:
I believe that national standards are related to actual damage.

Linda Brown:
For transparency considerations, it is important to state the basis for these characterization factors. It is important to present the models of risk assessment used. In calculating indicator's values, we have to look on uncertainties in input/output data itself, the potency equivalencies and these thresholds. There are uncertainties in all those levels and they have to be made transparent.

Mark Goedkoop:
The development of these methodologies deals with perceptions. One of the solutions is to look to government objectives because the civil servants are paid to deal with subjective arguments and make decisions. The model of Inaba is based on the political decision.

Linda Brown:
There is a fundamental difference between a scientific analysis of risk and the political decision of what is more important.

Martin Baitz:
Then the weighting will be made by the politicians, which may be insufficient.

Craig Boreiko (International Lead Management Center, U.S.A.):
I take the issue of sustainable development very seriously. The consequences of inaction are serious, but the consequences of inappropriate actions are equally serious and, in some cases, can be more so. It has been said that we need to have quick answers and that we have to act in the face of uncertainties. However, from the perspective of a toxicologist, much of the uncertainty with eco-indicators is not on the science side per se. Rather, it is in how to translate complex scientific issues into very simple models. According to the eco-indicators model presentation, the toxicological components operate on three premises: that dose responses are always linear and without thresholds; environmental concentration equals effect; and probability distribution approaches can be reliably used to assess eco-system impact. These assumptions are not true.
It is important to get it right. We know how to model many of the effects that are of concern here, but it is not easy to do. I am concerned that the drive for simplicity in models causes us to dismiss the complexity that characterizes toxicological issues. The simple solution to a complex problem is almost inevitably wrong. We can, and must, do better than this.

Mark Goedkoop:
I hope that by having a linear response we are not introducing too large an error, but we need, so far, to make that simplification to resolve the problem. The models will be refined in the future.

Martin Baitz:
It is a step towards a tool-boxtype of thinking. LCA or LCI is not the panacea but you can identify the hot spots of a very complex system and you can complete the information gathering with another tool and get a scientific answer to an identified special problem.

Diane Campbell (Natural Resources Canada):
How do you see the process addressing the factors of land use and bio-diversity?

Linda Brown:
Bio-diversity is outside the framework of LCA on a quantitative basis. What is proposed is to look at indicators of the actual depleted land area in the context of terrestrial habitat, aquatic habitat and soil. It is only a first step in the direction.

Mark Goedkoop:
In the 1997 method we will express damage to the ecosystem as potential effect on a fraction of species. This is more or less a bio-diversity indicator. The same indicator can be applied to land use such as agriculture. We realize that it is still primitive.

Kevin Brady:
In the LCA work, distinctions are made between internal and external applications. With internal application of LCA, inside a company, you are freer to do different things and to experiment. For public application, where you say something about the performance of your product in the market-place, a higher standard is expected. Do you see some distinctions in the eco-indicator tools between internal applications within a company and how they can be used by public decision-making bodies where they can, for example, make inter-material comparisons among steel, wood and plastic?

Martin Baitz:
There are no true or wrong weighting sets as such. There is no simple answer. Different panels will give you different weighting factors for the same impact. For the external use, one can use its own criteria if you say what you did and why or one can use a panel method, if you say which.

Linda Brown:
Internal vs external debate. The internal use of the model has external consequence to vendors and customers. The dichotomy is somewhat confusing. To make the information as useful as possible, it needs to be as accurate as possible at all levels. I cannot subscribe to the idea that the internal application should be less rigorous than the external level.

Mark Goedkoop:
We always say that eco-indicators are for internal use only. I do not have examples of companies using the eco-indicator model for marketing purposes.

Session 2: Users of the Models

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Eco Indicators, Customer Value and Environmental Leadership

Duncan Noble
Manager, Environment & Sustainability

Eco-Indicators for Products and Materials
- State of Play '97 Workshop
Toronto, 25 November 1997

Agenda

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- Why Eco Indicators?
- Nortel Overview
- Environmental Drivers
- Market Context
- From Materials to Systems
  - Lead-Free Technology
  - Butterfly Concept Telephone
  - Utility Networks
- Design Process Considerations
- Summary: Key Messages

Key Messages

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- Eco-indicators must be part of a comprehensive, integrated response to global environmental drivers
- Global environmental drivers affect businesses in several ways
  - Market Forces (Customers, Competitors)
  - Regulations & Taxes
  - Costs
- Range of business responses is diverse and at various levels (materials to systems)
- We need eco-indicators to implement strategy and to communicate with various stakeholders
  - Customers, Suppliers, Investors, Employees, Communities
- Not simply a social responsibility issue

Why Eco-Indicators?

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- Raise awareness: "Ask the right questions"
- Measure and encourage Continuous Improvement
- Drive Innovation
- Achieve Environmental Goals
- Respond to Market Pressures
- Implement Strategy

Nortel = Networks

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Nortel is a leading supplier of integrated network solutions for:

- **Information**
- **Communications**
- **Business**
- **Entertainment**
- **Education**

Number of Employees = 70,000

Operating in over 150 countries and territories

1996 Sales = $US 12.8 billion (20% growth from 1995)

Environmental Drivers

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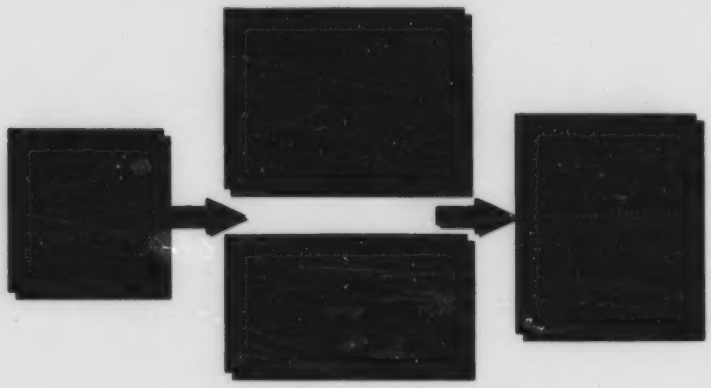
"If the entire world lived like North Americans, it would take three planet earths to support the present world population."



Evolution of Strategy

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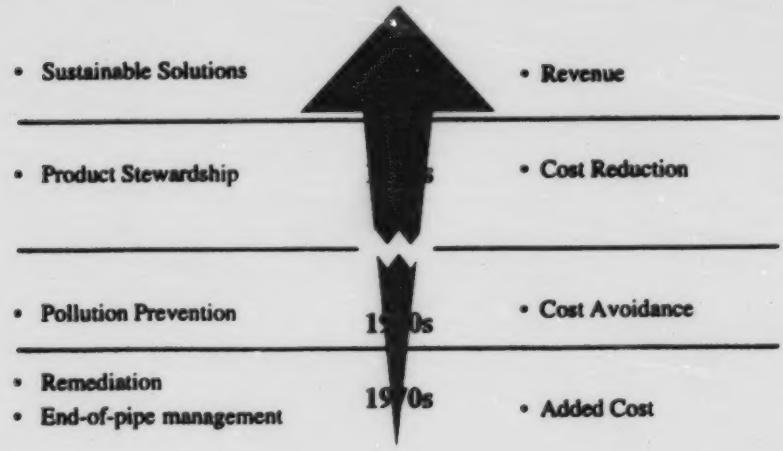

Environmental Policy

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Northern Telecom Limited (Nortel) is Committed to being a Leader in the Telecommunications Industry in Protecting and Enhancing the Environment. Wherever Nortel does Business, it will take the Initiative to Develop Innovative Solutions to Environmental Issues that may arise because of it's Products, Operations and Business Activities.

- **Compliance is a minimum requirement**
- **Customer value is a key concern**
- **We will share our knowledge**

Personal Concern Significant

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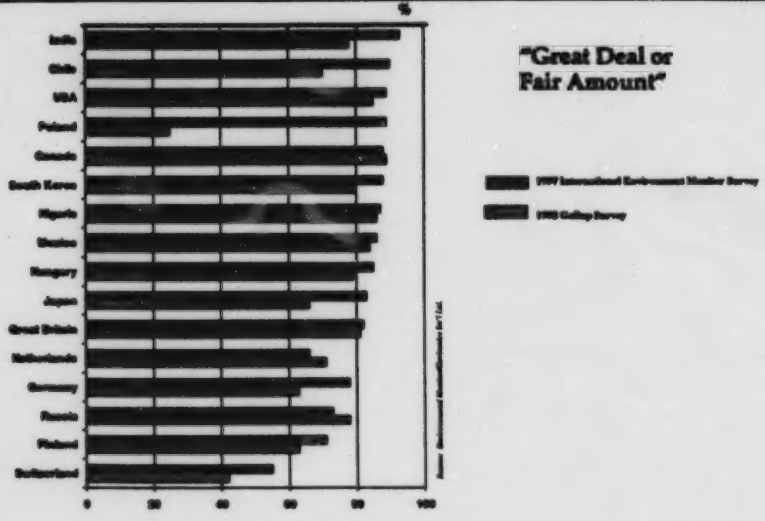

Customer Requests

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- Customer requests for Eco-information increased from 3 or 4 in 1995 to 3 or 4 a month in 1997 e.g. Telia, BT, Ameritech
- As part of the bid process e.g. MCI, Ameritech, Bell Canada, BT, Cable & Wireless, UK MOD, UniSource, Telia
- Main concerns are minimizing liability associated with the Hazardous Materials in Nortel products
- European Customers have wider interest in Design for Environment issues e.g. Eco-labels, Recyclability, Remanufacture, Energy Reduction, Packaging, Environmental Management Systems

Customer Priorities

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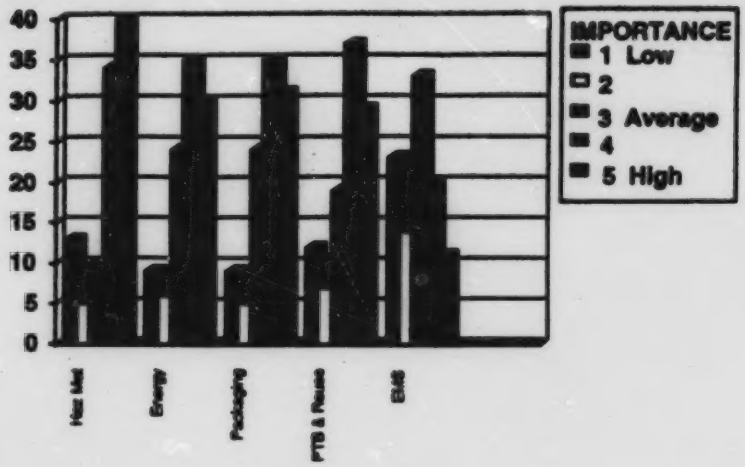

From Materials to Systems

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Lead-Free Technology

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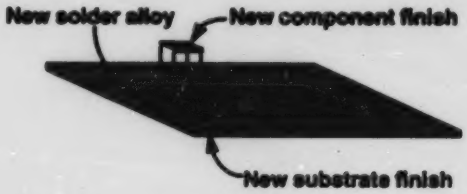

- Multicore Tin Copper Solder
  99.3% Tin, 0.7% Copper
- Lead-free component finishes
  Tin, Silver, Palladium, Nickel
- Entek 106 Board Coating - replacing HASL

Concept Telephone

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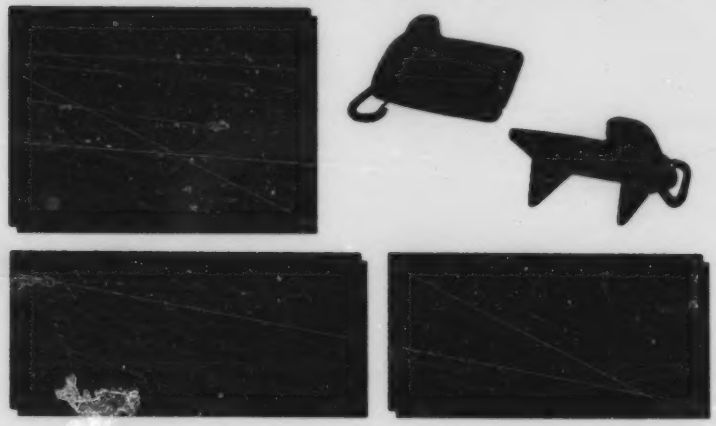
MISSION: Demonstrate value of DFE by building concept telephones with leading environmental features



Utility Networks

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- Information transfer over electrical power lines into homes at 10x speed of current fastest technology
- Electrical utilities can offer enhanced services using less stuff
- Uses existing infrastructure
  - no additional trenches dug, or lines strung

Design for Environment

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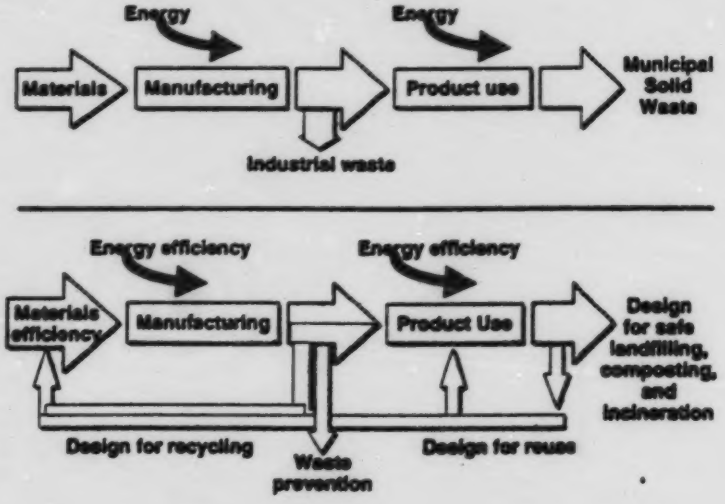

Design Process

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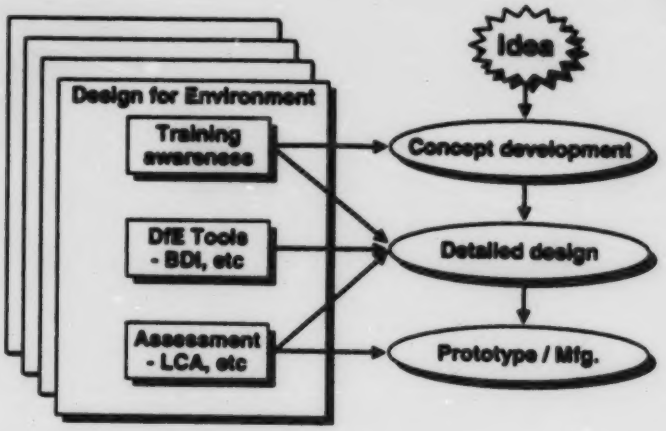

Summary

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- Eco-indicators must be part of a comprehensive, integrated response to global environmental drivers
- Global environmental drivers affect businesses in several ways (market pressures)
- Range of business responses is diverse and at various levels (materials to systems)
- We need eco-indicators to implement strategy and to communicate with stakeholders
  - Customers, Suppliers, Investors, Employees, Communities
- Not simply a social responsibility issue

For More Information

NORTEL
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- **Duncan Noble**

  Tel: (613) 235-5201

  Fax: (613) 235-9367

  Internet: duncan.noble@nortel.com

- **http://www.nortel.com/cool/environ/home.html**

EPS a Tool to Make LCAs Within Product Development Processes

Agneta Wendel, LCA manager, Volvo Car Corporation

Volvo Car Corporation has gradually implemented LCA within the product development process. Strategically the goal has been to fully delegate the environmental decisions as far as possible to the design engineers. The LCA tool should therefore fill the requirements of being quick to handle and to contain a reliable but easy visible result. The software should easily be able to compare two different alternatives and be used by non LCA practitioners. Due to this strategy EPS has been chosen as the main LCA tool at Volvo Car Corporation.

EPS was developed by IVL (Institute for Water and Air Conservation) in collaboration with the Federation of Swedish Industries and a number of other Swedish companies, including Volvo.

The EPS system is a flexible system for environmental priority setting. It meets the requirements of the ISO LCA standard 14040 and has a default set of value choices and data to be operable at an early stage in a product development procedure.

An environmental impact assessment with EPS is made with the aid of a unit known as ELU, Environmental Load Unit. The environmental impact is presented in the form of an index for different materials and processes. The ELU value represents the overall impact of a particular material or process on the environment, calculated per kg, litre, square metre etc.

Environmental Load Index x Quantity = Environmental Load Value

The ELU values can be used to select the alternative that presents the least negative impact on the environment at each stage of the design process.
The ELU values are based on the environmental impact of various substances and processes, divided into five objects to be safeguarded. These are :

- Biological diversity
- Health
- Biological production
- Natural resources
- Aesthetic values

The default valuation of environmental impacts reflects a philosophy where the environment as a resource is maximised including a minimisation of the damage probability. The system has been developed during many years and is described in several publications(1-5).

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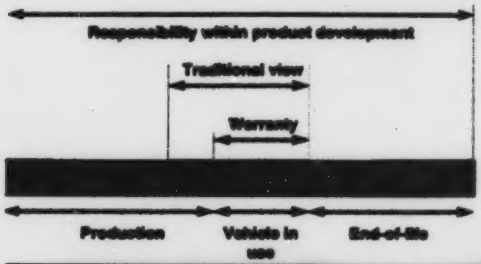
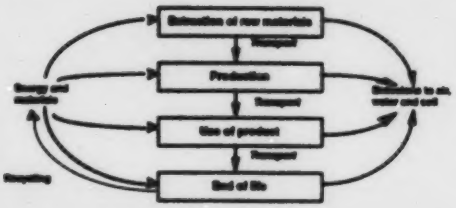
HOLISTIC VIEW



APPLIED ENVIRONMENTAL HOLISTIC VIEW



VOLVO VOLVO

EPS = Environmental Priority Strategies for product design

The goal has been to develop a tool that can be used by designers

HOW TO USE EPS ?

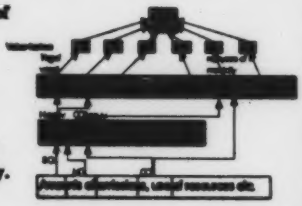
Environmental Priority Strategies in product design

Environmental impact value [ELU] = EPS index [ELU/SI Unit] * amount [SI Unit]

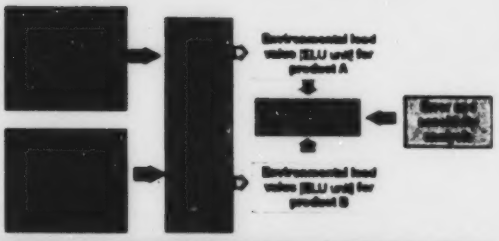
VOLVO VOLVO

The traceability principle

- The calculation of the measure of the total environmental impact must be made in a transparent and reproducible way.



EPS SOFTWARE



VOLVO VOLVO

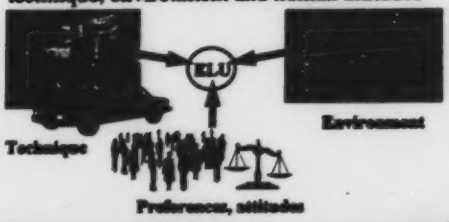
SAFEGUARD SUBJECTS

- Resources
- Human health
- Biodiversity
- Aesthetics
- Biological production

WHAT IS EPS ?

VOLVO VOLVO

The EPS-system combines scenarios for technique, environment and human attitudes



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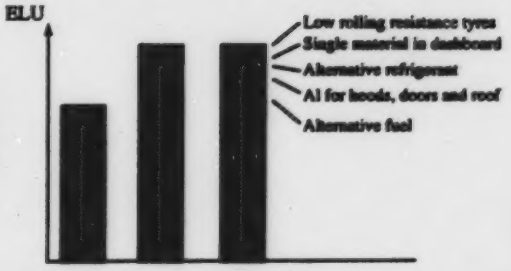
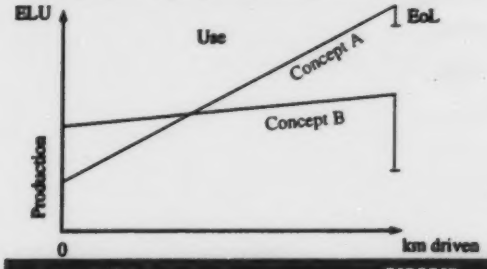


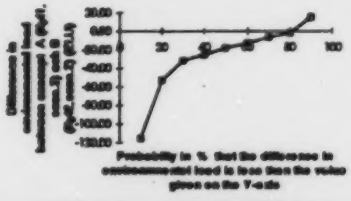
VOLVO

Environmental Comparision between two alternatives



VOLVO

Analysis of significance



VOLVO

SPINE

- Sustainable
- Product
- Information
- Network for the
- Environment

VOLVO

A summary of basic principles of the EPS system

- A holistic perspective
- A common measure for instance ELU
- All generations equal right to a good environment
- Default scenarios
- Transparency
- Precautionary principle
- Including uncertainty
- Default valuation from willingness to pay to prevent changes in safe guard subjects

VOLVO

A Second-Generation Environmental Performance Assessment System for Buildings

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Introduction

We live in an era that places high demands on the quality and performance of products. Consumers of household products are now able to obtain factual reports on the performance of toasters, cars and electronic equipment, and they are also becoming used to seeing product labels that symbolize the achievement of certain levels of performance. Can buildings be far behind?

The answer is not straight-forward. The testing and labelling of buildings is in its infancy, unless one includes the well-established rating of hotels and restaurants, both of which focus more on the service than the building itself. The agencies that test and label building materials and products are also well established and accepted, but there is a major difference between the kind of criteria that can successfully characterize components and those that need to be developed if one is to make meaningful assessments at the whole-building level. In addition, there is no concensus yet on the range of performance characteristics that should be covered, nor how much rigour needs to be applied in the application of such a system.

However, there is increasing interest in some sort of robust and validated system that can provide comprehensive performance assessments of buildings. Further, there is a need for a model that can encompass the wide variety of physical conditions, building traditions and environmental priorities that occur in different countries and in regions within countries. This paper describes the features of a model that has been designed through an international collaborative process to meet these objectives.

The Green Building Challenge Project in Brief

Before getting into details and issues, it will be useful to have a short overview of the project, called *Green Building Challenge'98* (GBC '98). It should be noted that GBC '98 consists of two related elements: a two-year process of developing and testing a performance assessment model, called Green Building Assessment Tool (GBA Tool), and an international conference to mark the end of this process. The overall goal of *GBC '98* is to test and demonstrate an improved method for measuring building performance, and then to inform the international community of scientists, designers and builders about the results. The project was initiated by Canada, but is being carried out in partnership with representatives from thirteen other countries.

Specific objectives of GBC '98 include:

- To develop a second-generation method for assessing building performance, with an emphasis on energy and environmental performance;
- To develop the method through an international and collaborative process;

- To test the system on buildings in each participating country; and
- To report on the results of the process in an international conference.

The process involves the development of a framework and methodology designed to assess the energy and environmental performance of buildings. The assessment framework builds on the experience developed in first-generation systems developed in the UK, Canada, USA, Netherlands, Norway and elsewhere. The system is being developed with a core component reflecting global issues, but this will be complemented by overlays reflecting energy, environmental and other priorities in specific countries and regions. National teams will develop these overlays and will also develop reference building criteria against which specific candidate buildings can be compared in a meaningful way.

The system will be used in 1998 to develop detailed performance assessments of over 30 comparable buildings from the participating countries, within a non-competitive process. It is expected that the resulting assessments will provide a unique view of environmental progress in participating countries as well as comparisons at the global level. Results of the detailed assessments and an analysis of the process will be presented at an international conference in Vancouver, Canada during October 1998.

Existing Assessment Systems

There are several first-generation environmental performance assessment systems which are relevant as background, but we will provide a quick overview of only three of these in this paper.

BREEAM

The first and most widely known is the Building Research Establishment Environmental Assessment System (BREEAM)[1], which is jointly operated by the Building Research Establishment (BRE) and a private firm, ECD Ltd. The system is designed as a green labelling system for buildings and building owners who use it (for the payment of a fee of about $6000), are free to use the resulting certificates for marketing purposes. Sub-variants of the system have been developed for office buildings, shopping centres, schools and other building types.

BREEAM is widely advertised and take-up of the program in the most widely applied variant, for office buildings, is estimated at between 15% and 20% of all new office building construction in England. BRE and ECD are encouraging the adoption of the system in several other countries, with some success so far, although many countries are using BREEAM as a reference document rather than adopting it whole, reflecting the fact that the system was not originally designed to accommodate national or regional variations.

A major effort is being made to implant the system in Canada, led by a Canadian ECD office and the Canadian Standards Association (CSA), which has issued the BREEAM Canada system as a guideline document. The extent to which the Canadian modifications to BREEAM have been validated is unknown. As a trial, CETC commissioned ECD Canada to undertake an assessment of a C-2000 building (Green on the Grand), and the report was completed in November 1996.

BEPAC

Another first-generation system is the Building Environmental Performance Assessment Criteria (BEPAC)[2] system, developed at the School of Architecture, University of British Columbia. The developers had the advantage of having BREEAM as a prior model, and the result is that BEPAC is more detailed and comprehensive than the first BREEAM variants, although BEPAC is limited to office buildings. Work has been done in Ontario and Nova Scotia to develop variants suitable for those regions, and some training of assessors is

currently going on in Vancouver. However, the BEPAC Foundation (the owner of the system) has oriented its efforts towards carrying out a small number of in-depth trial assessments rather than attempting to establish a widely used green labelling system and the system is somewhat expensive and complex to apply. The main value of the system is therefore for in-depth assessments and in the lessons it offers for the development of new systems.

LEED

The U.S. Green Building Council (USGBC) has launched a system designed specifically for use as a green labelling system for rating the performance of commercial office buildings. The system, known as Leadership in Energy and Environmental Design (LEED), is very simple in its structure in that all criteria are placed at the same level of importance. However, the criteria in the system are linked to a series of existing performance standards established by other credible bodies, which is an asset. Also, an elaborate management system has been established to implement it and several major industrial suppliers are strong backers, which give the system a significant chance for widespread adoption in the U.S.A.

Genesis of the GBC '98 Project

International projects are always expensive. Why, then, has this ambitious project to develop an environmental performance assessment system been launched, especially when several systems already exist?

Beyond the normal factor of researchers being unable the resist an interesting technical challenge, there are a number of logical reasons why the project is of interest to the sponsoring agencies. Briefly stated, these can be ascribed to the general currency of the issue, the nature of existing assessment systems, and the emerging need and potential for performance assessment methodologies to serve as the basis of eco-labelling systems.

The general subject area is certainly of general interest. It can be seen as a convergence of theoreticians and industry practitioners; the former searching for practical and broader implementation of Life Cycle Analysis (LCA) concepts, and the latter looking for measurable and objective indicators of performance. The take-up of BREEAM in England is an indicator of industry interest, and several other countries have launched studies to establish their own systems of eco-labelling within recent years, including Norway, Sweden, Finland, the Netherlands and Hong Kong.

Design limitations of existing systems

Although the BREEAM, BEPAC and LEED systems are all ground-breaking initiatives, there are certain factors which are likely to limit their widespread application:

1. Conceptually they are not structured to handle different levels of assessment, e.g., it is difficult to logically simplify BEPAC or to expand on BREEAM and LEED for more in-depth assessments;

2. They were not explicitly designed to handle regional-specific issues. For example, although several countries are using BREEAM or variants of it, the system was not originally designed to accommodate national or regional variations and the various customized versions do not emerge logically out of the source documents;

3. Although these established systems were intended for use as assessment tools, they have also been pressed into service by designers as design tools. Environmental assessment methods present an organized set of selected environmental criteria, but need further elaboration if they are to effectively guide designers on the many alternative ways in which a single performance criterion may be achieved.

These difficulties relate to the basic structure of these programs. A framework intended to handle regionally-specific issues in relation to a common core set of considerations must be designed from the outset to handle a wide range of parameters. A tool designed to provide guidance on design requires the development of considerably more detailed information than one intended for simple, or even detailed, assessments. The "first-generation" frameworks are not designed to address these multiple functions, even though they are closely related.

There is an obvious advantage if a tool can be developed that will, with various adjustments, handle the related functions of simple assessments, detailed assessments and design guideline formulation. A basic requirement for such a capability is that the information handled at one level of detail must be consistent, in terminology and approach, with information handled at another level of abstraction. Thus, a series of variables providing design *guidance* on, for example, energy-efficiency in mechanical ventilation systems, should be compatible with the range of variables covered in the detailed *assessment* of the performance of such a system and this, in turn, should be upwardly compatible with a broad-brush assessment of the same system.

An attempt is being made to implement such an approach in the GBC '98 assessment framework.

Potential Applications

The field of performance assessment is in its infancy, but there is intense interest around the world in developing systems that combines robustness, sophistication and an ability to reflect regional or national values. Such systems must meet basic applications, given suitable modifications.

1. For the detailed assessment of buildings, to determine renovation needs, or to specify required levels of performance.
2. As a design guideline tool, although the system must be elaborated for such use.
3. The application with the most potential for significant impact, however, is as a simplified performance assessment system for the purpose of awarding green labels or eco-labels, either to encourage market demand for high performance by potential tenants, or to determine the eligibility of owners for favourable tax treatment.

A performance labelling system that is to be widely used requires the establishment of an organization to manage the process of data collection, training, assessments and data analysis. There is also a need for extensive marketing of the system, which necessitates the active participation of one or more major private-sector partners. These are very modest barriers in light of the potential benefits.

The Design of the GBC '98 Green Building Assessment Tool (GBA Tool)

Design Goals

The assessment model designed for GBC '98 is known as the Green Building Assessment Tool, or GBA Tool. The chief design goals of the GBA Tool can be summarized in the following points:

- to design a system that can be modified to suit variations in national, regional and building type characteristics;

- to focus on relativistic assessments, by relating assessments to benchmarks that are based on applicable regulations or industry norms in each of the participating regions;
- to establish a structure that can be used at various levels of detail, from broad-brush assessments to detailed ones;
- to establish a structure that, while suitable for immediate GBC '98 purposes, can also be subsequently expanded as a design guideline system;
- to ensure consistency between levels of assessment, to the point where subcriteria form the complete and logical subsets of the criteria under which they are nested;
- to ensure consistency and rigor in terminology;
- to establish a scoring system that accepts both hard and soft data in a similar format;
- to include a weighting system that has defaults, but is user-modifiable;
- to implement the system in a software system that will facilitate the work of making regional modifications, and that will also simplify the task of inputting building data and assessing candidate buildings.

The design of the framework began in the summer of 1996 and underwent several iterations in its design, based on extensive feedback from the International Framework Committee (IFC), the committee that contains representation from all participating National teams. It should also be noted that the related process called Annex 31, sponsored by the International Energy Agency, is contributing a considerable amount of input to the process.

Design Features of GBA Tool

The core GBA Tool framework has now been completed, and its features can be summarized as follows:

- Parameters descend in generality from Sections to Performance Categories to Criteria and, at the most detailed level, Sub-Criteria;
- a scoring system has been established that ranges from -2 to +5, with the 0 level being the benchmark level that are based on regulations where applicable or, in their absence, based on industry norms;
- significantly inferior performance is scored as -2, while +5 represents a positive level of performance that is extremely difficult to reach;
- each parameter contains written statements related to each relevant score so that assessors can relate the actual performance to the nearest relevant statement, and National Teams can modify these statements within limits (see Appendix 1A and 1B for examples from the Office module);
- weighting is possible at both the sub-criterion and criterion level, again modifiable by National Teams;
- criteria and sub-criteria can be declared critical at the option of National Teams, and failure to meet a critical level can disqualify the subject building;
- versions of the system are being prepared for each of three major building categories: office buildings, multi-unit residential buildings and schools. These were selected by the IFC as representing some of the most generic building types extant, thereby maximizing the value of international comparisons; and
- the GBA Tool system is being implemented in the form of two distinct software modules; a Green Building Input (GBI) module, and a Green Building Assessment (GBA) module.

These modules are being developed within a user-friendly database program. Conceptually, the system is relatively simple, although both modules include some calculation fields. The software system is also intended to facilitate the work of National Teams in specifying the characteristics of hypothetical reference buildings to serve as benchmarks, and in modifying scoring statements and weighting values.

The completed framework covers issues that are given in-depth assessments down to the level of sub-criteria. These include four *Resource Consumption* categories, four *Environmental Loadings* categories and five categories relating to *Quality of the Indoor Environment*. Other sections deal with *Longevity, Process* and *Contextual Factors*, which are assessed only at an upper (Criterion) level. The current organization reflects the view of the IFC that in a process with limited time
and resources, there is a need to focus the detailed assessments on factors that are most germane to the goals of the process, e.g. resource consumption, environmental loadings and health/comfort issues.

Embodied Energy and Emissions

It will be noted that the structure of the GBA Tool framework (see Appendix 2 for the Office module) includes headings for embodied energy and airborne emissions, and that the software Input module provides tables for describing the type and quantities of materials of Subject buildings and their provenance. However, the Assessment module has left the embodied energy and emissions of materials as inoperative at this time. This contradiction reflects a consideration of the considerable workload that would result from an attempt to characterize all relevant extraction, production and transportation factors for materials and components, all related to the relatively minor impact that variations in embodied energy and emissions performance would have within the context of the total framework. We have asked national teams to gather information about the materials and components used in the subject buildings, so that a post-facto estimate of embodied energy and emissions might be carried out in the Spring of 1998, assuming that we and the national teams may by that time have developed some short-cut methods to make such estimates.

Potential v. Actual Performance

One feature that currently limits the application of the GBA Tool is that the current version only supports the assessment of what we term the *potential* performance of buildings, and not the *actual* performance, as in a fully occupied building.

Many would argue that the *actual* performance of the building in use is most meaningful to assess, since this is what ultimately affects the environment. Despite these compelling arguments, other considerations has led the designers to focus on assessing the *potential* performance of case-study buildings. Beyond external factors such as specific weather conditions during a specific time period, actual performance depends on the actual behaviour of occupants, tenants and building operators, and this brings into play many idiosyncratic factors that are not generally applicable.

On the other hand, the assessment of potential performance is based on assuming normal or default patterns of occupant behaviour and building operation. Although this is less "real", it produces vastly more useful information to guide the future actions of developers, owners, designers and anyone else who is involved with the production of buildings. A strong focus on actual performance can be useful if the intent is to influence the behaviour of tenants or occupants, but this is too complex and broad an issue to enter into for the GBA Tool at this time.

The focus on *potential* performance does not mean that occupied buildings will be excluded from assessments, but it does mean that performance parameters have to be tied to

information generated at the design stage, including specified systems and materials and default assumptions for modes of operation and occupancy.

Future Linkage to Other External Models

The designers envisage GBA Tool as a general model of building performance, with an emphasis on energy and environmental performance. GBA Tool does not itself incorporate specialized calculations, such as for energy simulation (e.g. DOE2) or the calculation of embodied energy (e.g. ATHENA); but it is hoped that linkages will be made with such models in the future, so that GBA Tool become an integrating platform or "engine" for some of these other more specialized models.

Conclusions

The presentation of the results of this ambitious process at the GBC '98 conference in October 1998, should be not be viewed as an end-point. We may be closer to achieving consensus on what factors collectively constitute excellence in environmental performance, but it is likely that much further work will be necessary to position the system as an implementable system in the industry. Given this, it is likely that the process will continue and that a GBC 2000 conference will take place in another country.

Nevertheless, the completion of the GBA Tool assessment framework will see the beginning of a serious effort, in cooperation with Canadian, foreign agencies, and private-sector corporations, to develop a workable industry assessment model, in parallel with continuing efforts to improve the basic model.

In addition, work will begin this fall to extend the system so that it can serve as a related guideline system for building designers and developers. The GBA Tool could be pressed into service for this purpose, but to make it a fully effective guideline system many specific recommendations will have to be prepared that relate to each assessment parameter. In addition, the high cost of developing hypotethical reference buildings to serve as benchmarks would have to be reduced; possibly by developing a library of off-the-shelf stock reference buildings or benchmarks based on archetypes of common building types and forms.

The development of the core GBA Tool is now complete, but it will only be possible to evaluate success or failure after national teams have gone through the process of adapting it to their own conditions and have tested it on several projects each. Considering the effort, resources and collective expertise of the sponsoring countries that is going into its development, however, it is likely to at least make a substantial contribution to the state-of-the-art.

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1. Prior, J. (Ed) (1993) *Building Research Establishment Environmental Assessment Method*, (BREEAM) Version 1/93 New Offices, Building Research Establishment Report, Second Edition.
2. Cole, R.J., Rousseau, D., and Theaker, I.T. (1993) *Building Environmental Performance Assessment Criteria: Version 1 - Office Buildings*, The BEPAC Foundation, Vancouver, December 1993.
3. U.S. Green Building Council, (1996) *LEED (Buildings: Leadership in Energy and Environmental Design), Environmental Building rating System Criteria*, Third Ballot Draft, 30th April 1996

4. *Energy and Environmental Assessment for the Office Building Sector: Executive Interviews and Tenant Survey;* Angus Reid Group for the Efficiency and Alternative Energy Branch, Natural Resources Canada; Unpublished study, October 1994.

Appendix 1A: Scoring Statements & Related Information for Sub-Criterion

R1.3 Operating energy consumption

The energy associated with building operation and use (lighting, heating cooling, ventilation etc.) typically represents the largest proportion of life-cycle energy use. Reducing operating energy represents on of the most critical performance requirements of green buildings.

Intention

To assess the extent to which the operating energy consumption for the case-study building is less or more than that of a *Reference Building*.

Performance Indicator

The annual GJ/m^2 of net usable building area; projected by computer simulation for buildings not yet constructed and with validation by actual energy use data for constructed buildings. See also Volume 5: *Simulation Appendix* for further detail.

Reference

The annual operating energy of a hypothetical *Reference Building* of the same function and occupancy, net usable floor area, and location as the case study building, and reflecting design and energy performance characteristics required by regulation or typical for the region.

Designation of Criticality: YES

Performance Scale:

Score	Default Performance
-2	The annual operating energy per m ^{2} of net usable floor area of the case-study building is 45% GREATER than that of the Reference Building.
-1	The annual operating energy per m ^{2} of net usable floor area of the case-study building is 20% GREATER than that of the Reference Building.
0	The annual operating energy per m ^{2} of net usable floor area of the case-study building is EQUIVALENT to the Reference Building.
1	The annual operating energy per m ^{2} of net usable floor area of the case-study building is 25% LESS than that of the Reference Building.
2	The annual operating energy per m ^{2} of net usable floor area of the case-study building is 40% LESS than that of the Reference Building.
3	The annual operating energy per m ^{2} of net usable floor area of the case-study building is 55% LESS than that of the Reference Building.
4	The annual operating energy per m ^{2} of net usable floor area of the case-study building is 65% LESS than that of the Reference Building.
5	The annual operating energy per m ^{2} of net usable floor area of the case-study building is 80% LESS than that of the Reference Building.

(Assessment notes not shown for brevity)

Appendix 1B: Scoring Statements & Related Information for Sub-Criterion

E1.5.1 CFCs and HCFCs emissions from building operations

Though refrigerants with relatively low ODP are becoming widely available in cooling equipment of all types and sizes, CFC-based materials continue to be used with regularity.

Intention
To assess the total amount of refrigerant on site dedicated to mechanical cooling equipment for HVAC purposes, including any stockpiled inventories (on or off-site) necessary for service or future use.

Performance Indicator
kg CFC-11 equivalent per m^2 of usable floor area

Reference
The amount of Ozone Depleting Substances per unit area of net usable building area of a hypothetical *Reference Building* of the same function and occupancy, net usable building area, and location as the case study building employing a CFC-11 chiller of typically appropriate size and configuration without refrigerant containment or recovery systems.

Designation of Criticality: YES

Performance Scale:

Score	Default Performance
-2	The Ozone Depleting Potential Index (DPI) associated with any CFCs and HCFCs used for building operations is 70% GREATER than that of the Reference Building
-1	The Ozone Depleting Potential Index (ODPI) associated with any CFCs and HCFCs used for building operations is 35% GREATER than that of the Reference Building
0	Ozone Depleting Potential Index (ODPI) associated with any CFCs and HCFCs used for building operations is EQUIVALENT to that of the Reference Building
1	The Ozone Depleting Potential Index (ODPI) associated with any CFCs and HCFCs used for mechanical cooling is 30% LESS than that of the Reference Building.
2	The Ozone Depleting Potential Index (ODPI) associated with any CFCs and HCFCs used for building operations is 55% LESS than that of the Reference Building.
3	The Ozone Depleting Potential Index (ODPI) for building operations is 70% LESS than that of the Reference Building.
4	The Ozone Depleting Potential Index (ODPI) associated with any CFCs and HCFCs used for building operations is 85% LESS than that of the Reference Building.
5	NO CFCs and HCFCs are used for building operations.

Assessment Notes

1. On or off-site ODS inventories are considered to include all estimated future ODS material requirements through the life service life of the equipment regardless of whether such inventories *physically* exist. In this manner indirect credit is given for ODS containment/recovery/scavenging systems.

Appendix 2: GBA Tool Office Framework

GBC '98 Performance Categories, Criteria and Sub-Criteria

Office Buildings - Final

November 12, 1997

Note: Criteria or sub-criteria marked in italics are not operational at this time

RESOURCE CONSUMPTION

	Wt.	Wt.
R1 ENERGY		
R1.1 Embodied energy for initial production	0.00	
R1.2 Embodied energy consumption for recurring production	0.00	
R1.3 Energy consumption for building operations	0.75	
R1.4 Embodied energy consumption for decommissioning	0.00	
R1.5 Peak demand	0.25	
R1.5.1 Peak electrical demand		0.33
R1.5.2 Peak natural gas demand		0.33
R1.5.3 Peak heat demand (if district heating)		0.33
R1.6 Thermodynamic matching of fuel type and end use	0.00	
R2 LAND		
R2.1 Initial ecological significance and scarcity of land used	0.33	
R2.2 Efficiency of land use	0.33	
R2.3 Maintenance of site biodiversity and ecology on building site	0.33	
R3 WATER		
R3.1 Potable water consumption for building operation use	0.50	
R3.2 Potable water consumption for landscaping irrigation	0.50	
R4 MATERIALS		
R4.1 Retention of existing building for new uses	0.70	
R4.2 Efficiency of material use	0.10	
R4.2.1 Efficient use of structural materials		0.33
R4.2.2 Efficient use of architectural materials		0.33
R4.2.3 Efficient use of finishing materials		0.33
R4.3 Source and type of materials	0.20	
R4.3.1 Minimum use of scarce material resources		0.33
R4.3.2 Use of salvaged materials, components and systems		0.33
R4.3.3 Use of materials with high post-consumer recycled content		0.33

ENVIRONMENTAL LOADINGS

E1 AIRBORNE EMISSIONS		
E1.1 CO_2 emissions	0.45	
E1.1.1 CO_2 emissions from initial building production		0.00
E1.1.2 CO_2 emissions from recurring production		0.00
E1.1.3 CO_2 emissions from building operations		1.00
E1.2 SO_2 emissions	0.10	
E1.2.1 SO_2 emissions from initial building production		0.00
E1.2.2 SO_2 emissions from recurring production		0.00
E1.2.3 SO_2 emissions from building operations		1.00
E1.3 NOx emissions	0.10	
E1.3.1 NOx emissions from initial building production		0.00
E1.3.2 NOx emissions from recurring production		0.00
E1.3.3 NOx emissions from building operations		1.00
E1.4 Particulate emissions	0.10	
E1.4.1 Particulate emissions from initial building production		0.00
E1.4.2 Particulate emissions from recurring production		0.00
E1.4.3 Particulate emissions from building operations		1.00
E1.5 CFCs, HCFCs and Halon emissions	0.25	
E1.5.1 CFCs and HCFCs emissions from building operations		0.50
E1.5.2 Halon emissions from building operations		0.50

L2 SOLID WASTE		
E2.1 Solid waste from building operations	0.75	
E2.1.1 Dedicated recycling storage and handling areas and systems		0.50
E2.1.2 Organic waste separation and composting		0.50
E2.2 Solid waste in future decommissioning	0.25	
E2.2.1 Potential recoverability of materials and components		0.50
E2.2.2 Potential reuse of materials and components		0.50
L3 LIQUID WASTE		
E3.1 Sanitary waste flows to municipal system	0.60	
E3.1.1 Quantity of black water flows to municipal system		0.50
E3.1.2 Quantity of grey water flows to municipal system		0.50
E3.2 Storm water waste flows to municipal system	0.40	
E3.2.1 Peak load for municipal storm water system		0.50
E3.2.2 On-site measures for storm water treatment		0.50
E4 OTHER LOADINGS		
E4.1 Measures taken to control private auto usage	0.50	
E4.1.1 Limitation on provision of car-parking		0.25
E4.1.2 Provision of dedicated carpooling parking		0.25
E4.1.3 Provision of bicycle parking facilities		0.25
E4.1.4 Provision of change facilities		0.25
E4.2 Nuclear waste hazards	0.50	
E4.3 Other hazardous wastes	0.00	

QUALITY OF INDOOR ENVIRONMENT

Q1 AIR QUALITY		
Q1.1 Moisture control	0.33	
Q1.1.1 Control of moisture in building envelope that may affect IAQ		0.33
Q1.1.2 Control of standing water in cooling towers		0.33
Q1.1.3 Control of standing water in HVAC distribution systems		0.33
Q1.2 Pollutant source control	0.33	
Q1.2.1 Mineral fibre control		0.25
Q1.2.2 VOC emissions control		0.25
Q1.2.3 Control of pollution migration between occupancies		0.25
Q1.2.4 Radon control measures		0.25
Q1.3 Ventilation and fresh air delivery	0.33	
Q1.3.1 Quality of outdoor supply air		0.20
Q1.3.2 Quantity of outdoor air supplied		0.20
Q1.3.3 Filtration performance in HVAC systems		0.20
Q1.3.4 Provision of adequate amount and location of operable windows		0.20
Q1.3.5 Ventilation effectiveness in occupant breathing zone		0.20
Q2 THERMAL QUALITY		
Q2.1 Maintenance of acceptable thermal comfort	0.50	
Q2.1.1 Maintenance of acceptable indoor thermal conditions		0.50
Q2.1.2 Minimization of solar overheating		0.50
Q2.2 Maintenance of acceptable relative humidity	0.50	
Q2.2.1 Maintenance of acceptable relative humidity during heating seasons		0.60
Q2.2.2 Maintenance of acceptable relative humidity during cooling seasons		0.40

Q3 VISUAL QUALITY

Q3.1 Contribution of daylight	0.20	
Q3.1.1 Daylighting of workplace areas		0.70
Q3.1.2 Daylighting of other areas		0.30
Q3.2 Appropriate illumination levels	0.20	
Q3.2.1 Appropriate illumination levels in workplace areas		0.70
Q3.2.2 Appropriate illumination levels in other areas		0.30
Q3.3 Avoidance of glare and reflections	0.20	
Q3.4 Luminaire and lamp performance	0.20	
Q3.4.1 Appropriate luminaire design		0.33
Q3.4.2 Colour rendition		0.33
Q3.4.3 Avoidance of lamp flicker		0.33
Q3.5 Visual contact with the exterior from workplace areas	0.20	
Q3.5.1 Visual access to exterior		0.50
Q3.5.2 Glazing visual transmission factor		0.50

Q4 NOISE AND ACOUSTICS

Q4.1 Appropriate noise attenuation through the building envelope	0.33
Q4.2 Control of building equipment noise transmission to workplace areas	0.33
Q4.3 Appropriate noise attenuation between occupied spaces	0.33

Q5 CONTROLLABILITY OF SYSTEMS

Q5.1 Level of building automation appropriate to system complexity	0.33
Q5.2 Capability for partial operation of building technical systems	0.33
Q5.3 Capability for personal control over indoor environment	0.33

LONGEVITY

L1 ADAPTABILITY

L1.1 Ease of adapting HVAC systems for changing tenant requirements	0.14
L1.2 Ease of adapting lighting systems for changing tenant requirements	0.14
L1.3 Ease of adapting electrical systems for changing tenant requirements	0.14
L1.4 Adequacy of floor-to-floor height for major change in uses	0.14
L1.5 Appropriateness of core and structural member location for major change in uses	0.14
L1.6 Potential for future upgrade of building envelope thermal performance	0.14
L1.7 Capability for future change of energy supply	0.14

L2 MAINTENANCE OF PERFORMANCE

L2.1 Selection of material durability appropriate to planned service life	0.17
L2.2 Protection of materials from destructive elements	0.17
L2.3 Ability to maintain performance under abnormal conditions	0.17
L2.4 Access to central technical systems for maintenance and replacement	0.17
L2.5 Access to distributed technical systems for maintenance and replacement	0.17
L2.6 Access to building elements and materials for maintenance and replacement	0.17

PROCESS

P1 DESIGN AND CONSTRUCTION PROCESS

P1.1 Provision of inter-disciplinary design team	0.17
P1.2 Development of explicit targets for major performance parameters	0.17
P1.3 Specification of environmentally-sensitive construction procedures	0.17
P1.4 Specification of construction and demolition waste strategy	0.17
P1.5 Appointment of commissioning agent and development of commissioning protocols	0.17
P1.6 Post construction/renovation flush-out	0.17

P2 BUILDING OPERATIONS PLANNING

P2.1 Provision of building and technical systems documentation	0.14
P2.2 Provision of building operational logs	0.14
P2.3 Plans for training of operating and maintenance staff	0.14
P2.4 Specification of preventative maintenance program	0.14
P2.5 Provision of tenant performance incentives in leases	0.14
P2.6 Plans for occupant environmental awareness program	0.14
P2.7 Plans for handling of hazardous solid and liquid wastes	0.14

CONTEXTUAL FACTORS

C1 LOCATION AND TRANSPORTATION

C1.1 Proximity to public transport	0.33
C1.2 Proximity to appropriate amenities and services	0.33
C1.3 Locational factors that may affect commercial transport usage	0.33

C2 LOADINGS ON IMMEDIATE SURROUNDINGS

C2.1 Interference with access to daylight of adjacent property	0.14
C2.2 Interference with access to winter sun of adjacent property	0.14
C2.3 Solar heat absorption and re-radiation from building surfaces	0.14
C2.4 Reflected glare from building surfaces	0.14
C2.5 Adverse wind conditions at grade	0.14
C2.6 Waste heat rejection from building equipment to outdoor public spaces	0.14
C2.7 Noise from building affecting adjacent properties	0.14

Session 3: Other Stakeholders

Environmental Assessment and Eco-Indicators in the U.S. EPA

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BACKGROUND

Recent programs in pollution prevention, life cycle analysis, and sustainable development require comprehensive environmental impact assessments to support decision making. Whereas traditional impact assessment provided sophisticated simulation of a single impact category within a single media; conducting more comprehensive impact assessments required practitioners to use less sophisticated techniques which in turn has lead to the creation of eco-indicators. Current programs need to determine if the simulations currently being used are sophisticated enough to support the decisions under study.

CURRENT EXAMPLES IN THE U.S. EPA

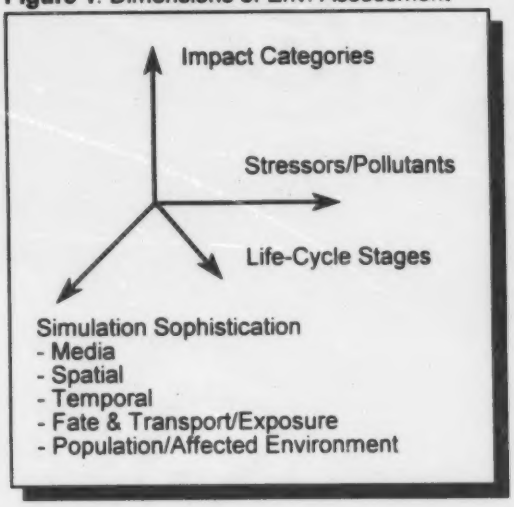
The ideal environmental impact assessment would provide infinite detail in all of the dimensions of environmental assessment. In reality, every environmental assessment is limited by the resources and data available; therefore, the first step in conducting a comprehensive impact assessment is the selection of the appropriate level of sophistication for each of the dimensions of the assessment.

Environmental assessment can be conducted from different perspectives with various goals and objectives. Assessments can be used to accomplish the following:

- To assist in the decision making process for implementation of pollution prevention or sustainability programs.
- To differentiate the environmental impacts of various production routes on one or more of the life cycle stages of a product.
- To evaluate, prioritize, and select optimal prevention and control options.

Based on the goal and scope of each study, the study may be defined in terms of impact categories, pollutants/stressors, life cycle stages, and simulation sophistication. Tradeoffs must be evaluated to determine if the boundaries, simulation sophistication, and data quality will support decision making to the level of certainty required for the study decision.

Figure 1. Dimensions of Env. Assessment



Several EPA programs and projects attempt to accomplish comprehensive environmental impact assessment for environmental decision making. These programs and projects include:

- TRACI (the Tool for the Reduction and Assessment of Chemical Impacts),
- the LCA Design Tool Kit,
- P2P (a Tool to Measure PP Progress)
- WMPT (the Waste Minimization and Prioritization Tool).

TRACI is a Windows-based tool being developed within U.S. EPA's ORD/NRMRL with the ability to conduct a screening level assessment in the following impact categories:

- stratospheric ozone depletion,
- global warming,
- acidification,
- eutrophication,
- photochemical oxidation,
- human health, and
- environmental health.

TRACI is expected to be released in 1998.

The LCA Design Tool Kit is being developed within the U.S. EPA's ORD/NRMRL and the University of Tennessee in conjunction with Saturn Corporation. It will allow LCA product design including Activity Based Costing, and screening and detailed LCA impact assessment. The LCA Design Tool Kit will include an LCA inventory database with data on: aluminum, steel, rubber, glass, and six plastic resins. The LCA Design Tool Kit is expected in 1998.

P2P is being developed within U.S. EPA's ORD/NRMRL with the next version - Mark III - capable of a screening level characterization. Currently 3000 chemicals are classified within 22 impact categories.

The Waste Minimization and Prioritization Tool is being developed by the U.S. EPA's Office of Solid Waste and Emergency Response. It allows a screening level evaluation of chemicals based on human and environmental health effects. The criteria for evaluation include persistence, bioaccumulation, and toxicity. It is being used for prioritization in a number of programs including the Persistent and Bioaccumulative Toxins (PBT) Initiative. A draft version was released in June 1997.

CONTINUING QUESTIONS

There are several issues related to eco-indicators which continue to be a concern in every comprehensive study. These include:

- determining the required simulation sophistication,
- the absence of high quality data,
- boundary effects,
- the necessary value choices, or scientific judgment that must be made during the process,
- the difficult but important role of uncertainty and sensitivity analysis,
- the recognition of secondary and related effects,
- the advantages and disadvantages to various normalization techniques,
- the need for decision making involving many unrelated impact categories, and
- the subjectivity involved in the valuation process.

SUMMARY

Eco-Indicators are in infancy stages at this point. Additional research and discussion is necessary to refine Eco-Indicators.

Environmental Assessment and Eco-Indicators in the U.S. EPA

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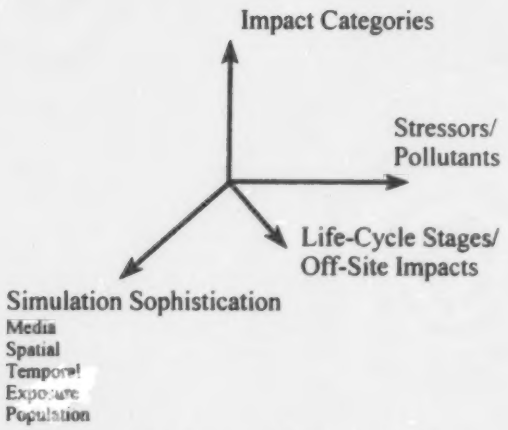
I AM Team Vision

Research, development, and application of environmental impact assessment and progress measurement for environmental decision making.

Presentation Plan

- Dimensions of Environmental Assessment
- Programs Utilizing Eco-Indicators
  - TRACI
  - LCA Design Tool Kit
  - P2P
  - WMPT
- Continuing Questions



TRACI

- Screening Tool designed to assist in Environmental Planning and Prioritizing.
- Optional Normalization and Valuation for Decision Making Framework.
- Extensive documentation and Hypertext Links to other Related Sites.
- Beta testing in 1998.

TRACI Impact Assessment Categories

Increasing International and Scientific Consensus

- Ozone Depletion
- Global Warming
- Acidification
- Eutrophication
- Photochemical Oxidation
- Human Health
- Environmental Health

LCA Design Tool Kit

- To evaluate manufactured products at the screening or detailed component level.
- Includes LCI data for: steel, aluminum, iron, rubber, plastics, coatings, and glass.
- Includes U.S. electricity generation grids.
- ABC System with Costing Database.
- Cofunded by Saturn and U of TN.

Design Tool Kit Categories

- Ozone Depletion
- Global Warming
- Hazardous Waste
- Solid Waste Landfill Space
- Non-renewable Res. Depl.
- Renewable Resource Depl.
- Acidification
- Photochemical Oxidation
- Chronic Human
- Acute Human
- Aquatic Toxicity
- Terrestrial/Avian Toxicity

P2P: A Tool to Measure PP Progress

- Developers: Gregory Carroll, David Pennington, & Robert Knodel
- Comparison of Products' Life Cycles and/or Specific Processes
- Provides Classification & Regulatory Info
- 3000 Chemicals & 22 Impact Categories
- Mark III Version will Provide Screening Level Characterization.

WMPT

- U.S./Canadian Great Lakes Binational Strategy calls for significant reduction to "virtual elimination" of PBTs.
- U.S. determining additional PBTs for Initiative ($14 M in FY99) Using Human and Environmental Health Eco-Indicators Based on PBT within WMPT (Waste Minimization and Prioritization Tool).

Questions for Discussion

- Determining Required Sophistication
  - Value Choices / Scientific Judgment
- Consistency in Decision making with Various Impact Categories
  - Various Normalization Techniques
  - Subjectivity in the Valuation Process

"To Include, Exclude, or Aggregate an Impact Category (or any Dimension of Environmental Assessment) is a Value Choice or Scientific Judgment."

Valuation Strengths & Weaknesses

- Pros
  - Consistent Decisionmaking Framework
  - Values become Transparent
  - Allows Analysis of Critical Valuations
  - Disaggregated Results may be Viewed
- Cons
  - Subjective
  - Little Guidance Currently Available
  - Dependent on Participants' Involved

Normalization Techniques

- Relative Contribution within Scale
  - Global issues minimized.
- Comparison to Reg. Limits or Thresholds
  - Only regulated chemicals / categories.
- Statistical Comparison
- Comparison to Background Concentrations
  - Statistical impact is not env. impact.
- Comparison to Baseline
  - Dependent upon baseline significance.

Areas of Concern

- Absence of High Quality Data
  - Toxicity, Fate, Transport, Inventory
- Gross Modeling Assumptions
  - Thresholds, Temporal, Spatial
- Life Cycle Boundary Effects
- Secondary and Related Effects
- Uncertainty & Sensitivity Analysis

Summary

- Lots of questions and concerns.
  - Determination of Sophistication
  - Inclusiveness of Impact Categories/Stressors
  - Normalization and Valuation
  - Uncertainty and Sensitivity Analysis
- Research and Discussions Necessary to Refine Eco-Indicators.

Environmental Performance Indicators – an ENGO Perspective

By Marlo Raynolds – Pembina Institute for Appropriate Development

Introduction

Environmental performance indicators are being used by industry to measure, monitor and communicate their environmental performance to a variety of audiences including internal decision makers, regulators, environmental groups, interested public, and customers. The message EPIs carry is whether or not sufficient improvements are being made. Internally, EPIs may be used to induce decisions and actions to continuously improve performance.

The Objectives of EPIs

- To measure the company's impact on the environment
  Environmental performance indicators provide a means to report the overall scale of impact the company's actions have on the environment.

- To measure the company's eco-efficiency
  Eco-efficiency is a ratio of the amount of resource inputs (e.g. raw materials, energy) and/or pollution outputs (e.g. air emissions, water effluents) per amount of useful product or service provided (e.g. products, profits, jobs). EPIs may be used to measure a company's eco-efficiency by reporting the amounts of pollution produced per unit of product.

- To compare environmental performance over time
  By setting up standard EPIs for a company or an entire industry, environmental performance can be recorded over time and monitored for continuous improvement. This promotes innovations to further improve performance.

- To compare actual performance with targets
  Once a company has set environmental performance goals and targets, EPIs provide a means to measure actual performance and monitor the progress in achieving those goals.

- To compare the company's performance with others
  Standard or common EPIs may be used industry wide to enable comparisons between companies. This helps drive technical innovations to improve the eco-efficiency of the entire industry.

- To raise awareness of employees and management within the company
  EPIs provide a means for the company to communicate internally the effects decisions may have on environmental performance and overall eco-efficiency. EPI information can be integrated into decision making which will induce environmental improvement.

- To raise awareness among external stakeholders
  As a communication tool, EPIs can effectively demonstrate to external stakeholders how the company is performing over time to reach its environmental performance goals and targets.

- To disclose information to regulators and shareholders
  A practical set of EPIs can be used effectively to report environmental performance to regulators and shareholders.

Effective EPIs

Single score environmental performance indicators with "imaginary" units are not effective in communicating environmental performance internally or externally. Too much information is lost by aggregating to a single score or an environmental "stamp of approval". Single score indicators become too complicated for external comparisons and are rarely scientifically justifiable. "Stamp of approval" type indicators such as the Environmental Choice Eco-Label do not promote continuous improvement and have little value once an entire industry carries the label.

An effective set of environmental performance indicators will communicate the most relevant and representative environmental performance information without an overwhelming amount of data collection and processing.

Effective EPIs should:

- reflect important factors that are meaningful and significant for the company and that relate to the carrying capacity of the regional and global environment;
- be suitable for the audience for which they are intended;
- be based on quantitative measurements, so as to be objective and verifiable;
- consider, where appropriate, the life cycle of products or services;
- be consistent and comparable to allow for comparisons over time and between organizations;
- relate to the goals and targets of the company;
- be practical in terms of being understandable and serving as a good proxy where specific measurements are not readily obtained;
- be affordable so that data gathering, compilation and reporting are not onerous; and
- be integrated into decision making so that information provided induces change toward innovations for continuous environmental improvement.

Two primary types of EPIs exist:

1□ Gross Environmental Performance Indicators

Gross indicators provide a measure of the absolute amounts of resource inputs or pollution outputs a company consumes or produces. These indicate the gross loading of environmental stressors which can be used for reporting, estimating cumulative impacts, and comparing to environmental and ecosystem carrying capacities.

2□ Eco-Efficiency Environmental Performance Indicators

Eco-efficiency indicators link resource inputs and/or pollution outputs to units of desirable outputs (e.g. products or services). These indicators provide information on the level of continuous improvement and allow comparison to similar competitive products, both of which promote innovation for further improvement.

An Example: Automotive Fuels

Today, manufacturers of automotive fuels may apply for a the Canadian Environmental Choice Logo, a "stamp of approval" type of eco-indicator. This EPI provides little information to the customer. The vast majority of customers have no idea of the requirements to obtain the logo. Even with the requirements known, an interested party can not obtain the supporting documentation the company submitted to obtain the right to use the logo. In addition, once a large number of fuel companies utilize the logo, customers have no means to differentiate products based on environmental performance. Furthermore, once the right to use the logo is obtained the company has no further incentive to innovate for continuous improvement.

A more useful set of eco-efficiency environmental performance indicators for automotive fuels would report:

1□ Combustion emissions of NOx, VOCs, and CO per unit of fuel energy,

2□ Life-cycle emissions of greenhouse gases per unit of fuel energy, and
3□ Combustion emissions of air toxics per unit of fuel energy.

All three of these are currently required to obtain the Environmental Choice Logo, but become hidden by the logo. By quantitatively reporting these three EPIs, customers can better compare their fuel choices. Companies are also motivated to invest in further improving the performance of their products.

It is also vital that the supporting documentation for the EPIs be made available to interested parties. The methodology and data must be transparent to allow for verification and accountability. This will drive industry to develop a more standardized method for measuring and reporting EPIs.

The Future of EPIs

The National Round Table on the Environment and the Economy Task Force on Eco-Efficiency recently concluded in their 1997 document "Backgrounder – Measuring Eco-Efficiency in Business", that there need to be

> "a few robust, widely accepted, quantifiable and verifiable eco-efficiency indicators that all companies can use."

The task force supports a move to comparative standards for industries, data availability, development of a transparent methodology, and a focus on promoting innovation. These ideas are setting the stage for the future of environmental performance indicators.

The future of EPIs requires companies to set performance goals and quantifiable targets, and to develop effective EPIs to measure progress, promote innovation and integrate into the decision making process to achieve continuous improvement.

Analysis of the Eco-indicator 95 Model

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Introduction

The Eco-indicator 95 model expands typical Life Cycle Assessment (LCA) methods. It includes weighting factors for a variety of adverse environmental impacts produced during the various stages of product production, use and disposal. This is done to "simplify" the interpretation of the often complex results of LCA analysis.

In view of implications for material procurement and use, a preliminary evaluation of the assumptions underlying the Eco-indicator 95 model has been undertaken. The main documents consulted were two papers published in English: *The Eco-indicator 95, Final Report*[6] and *The Eco-indicator 95, Manual for Designers*[7] and two softwares *Eco-it* and *Simapro* (both reports may be obtained from PRé Consultants[8]).

The ease of use of *Eco-it* software is the most interesting aspect for the product designer. By using the various building blocks, he/she can rapidly evaluate various options. The analyst can consult the *Simapro* software to get more detail on the environmental aspects of various materials and processes.

The Delft University in the Netherlands published the *IDEMAT*[9] package that includes eco-indicators for various industrial processes based on the Eco-indicator 95 methodology. The *Eco-it* software can import the *IDEMAT* data base.

We have evaluated certain components of the model such as the methodologies, the supporting data, and the outcomes of the model. This presentation is intended to focus on selected aspects of the model and its use, and to provide a description of issues arising from the model's application to material choice. An exhaustive review of all the benefits and limitations associated with this type of model would require a more detailed investigation.

What the designer sees

The designer who wants to develop an environmentally sound product may not be entirely cognizant of the environmental impacts of the material he or she specifies. If the designer wishes to take these adverse issues into consideration, he or she would find it useful to have a method or tool to rapidly calculate the environmental impacts implicit in the various material choices. Such impacts would include also the entire life-cycle of the product.

PRé Consultants developed the *Eco-it* software package based on the *Eco-indicator 95* model. The only input required by this software package is the quantity of material used, the service performance (useful life and energy requirement), and the disposal processes. The software includes a data base containing indicator values for the production of materials (metals, plastics, glass, paper), and the recycling and disposal processes. It also includes indicator values for transportation and energy use. The software is presented as a "black box," i.e., the designer is not shown the calculation, the origin of the indicators, or the methodology. (Slide 2)

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[6] M. Goedkoop, The Eco-indicator 95, Final Report, NOH report 9523

[7] The Eco-indicator 95, Manual for Designers NOH report 9524

[8] PRé Consultants, URL : http://www.pre.nl email info@pre.nl

[9] IDEMAT, Delft University, URL : http://www.io.tudelft.nl/research/mpo/

How does the system work?

According to the Eco-indicator 95 framework, various emissions such as SO_2 and NO_x cause some damage. (Slide 3)

To demonstrate the application of the model, the production of 1 MJ of thermal energy from the combustion of oil is presented (Slide 4).

These data were taken from Simapro and the result is in agreement with Eco-it. The eco-indicator score (0.15×10^{-3} Pt) is a function of the contribution of various emissions.

In the eco-indicator 95 model, for the effect of acidification, the emission of 1 kg of NO_x has an eco-indicator score of 0.061 Pt. From the Final Report,

- the relative effect of NO_x with respect to SO_2 as acidification potential is 0.7;
- a reduction factor of 10 is sought; and
- the actual dose per person in Europe is 113 kg of SO_2 .

The basic equation for calculating is:

$$(Pt/kg)_{impact\text{-}effect} = (\text{relative effect} \times \text{reduction factor}) / (\text{dose / person}) \quad (1)$$

The eco-indicator score is proportional to the impact. A perhaps unintended consequence of equation (1), is that a reduction of the global emission of SO_2 in Europe will lead to an increase in the nominal eco-indicator score.

(Slide 5) **If we accept** an eco-indicator score of 0.061 $(Pt/kg)_{NOx\text{-}acidification}$ when the "dose/person" was 113 kg SO_2 / person in 1988, then the eco-indicator score should follow this type of relation in function of the time:

$$(Pt/kg)_{NOx\text{-}acidification\text{-}19xx} = 0.061\ ((\text{dose / person})_{acification\ -\ 19xx} / (\text{dose / person})_{acidification\ -1988}) \quad (2)$$

By establishing a baseline for acidification (1988), any modification in the emission level for a constant population in 19xx will decrease / increase the eco-indicator score in the apppropriate direction

Application to lead

Architects and products designers can also use the data base IDEMAT that is based on the Eco-indicator 95 framework. (Slide 6) This database gives an eco-indicator score of 0.00694 Pt/ kg of lead for the production phase, but it concludes that "lead is extremely hazardous and use should be prevented".

The implicit assumption from IDEMAT is the direct relation between the general use of lead and the general population exposure.

What is the relation between the lead exposure and the intensity of lead use?

In London, the measured concentration of lead in the air decreases between 1985 and 1996 while

the consumption of refined lead increases in United Kingdom at the same time. (Slide 7) On the other hand, a good correlation in observed between the lead concentration in London and the lead emission from the transportation sector. (Slide 8)

In conclusion, a large proportion of the decrease in the urban lead concentration resulted from the phasing out of the antiknock compound tetra ethyl lead.

With a proper risk management, large decrease in the exposure can be acheive by targetting few products.

Design choice

With the Eco-indicator 95 framework, the designer is given the possibility of using primary or secondary material. At the end of product useful life, we can consider either recycling step or the final disposition in a landfill. (Slide 9)

The recycling accounting method promoted by the Eco-indicator 95 is the open loop recycling. By the eco-indicator score it promotes the recycling only once. Using the Eco-indicator 95 methodology, the designer will not see the value for the reuse of recycled material. As metals are extensively commercially recycled, the designers usually ignore the recycle content in his component as it is not easy to know the origin of a metal part.

The closed loop approach should be used to capture the value of the metals. The primary metal production is used to make products and to replace material that is lost to the environment. All the losses to the environment from either primary or secondary production will be replaced by primary production. Accordingly no discrimination should be based on the origin of the metal but the design should promote recycling. (Slide 10)

Data quality

The concept of data quality is inherent to any scientific activity. To built their data base, the developer used various studies available in the open literature. Some time the emissions under consideration in those studies are different from the Eco-indicator 95 model. For example the primary reference related to the production of aluminum does not consider the PAHs emissions. When the boundary conditions of the literature study are different from the Eco-indicator 95, no adjustment is made. On several occasions, the eco-indicator score is significantly biased toward lower values.

Local conditions

As an example, one of the concerns regarding the effect of the emissions of SO_2 is the generation of winter smog. In Europe, the origin of the problem is mainly the combustion of low quality coal. The production of copper and nickel is associate to the generation of SO_2. Europe imports a significant proportion on copper and nickel in relation to his consumption. The Eco-indicator 95 model considers that the SO_2 emissions are always associate to the winter smog effect irrespectively where the metal is produced. In Canada, as we have winter but no winter smog related to smelting, the eco-indicator score for copper and nickel is not relevant.

Conclusions

Designers are using some type of eco-indicators models to improve their products and *Eco-it* is one of the tool that they are using. To ensure better quality of the decisions made by the designers using the eco-indicator scoring method, those points need to be considered:

- refining the basic equation ;
- consideration for avenue of product stewardship ;
- better acknowledgement for the recycling of metals ;
- refining the data modeling to ensure compatibility in the boundary definitions ; and
- consideration for wider environmental impact conditions outside Europe.

(Slide 11)

Acknowledgment

The Mining Association of Canada supported financially this work.

Analysis of the Eco-indicator 95 Model

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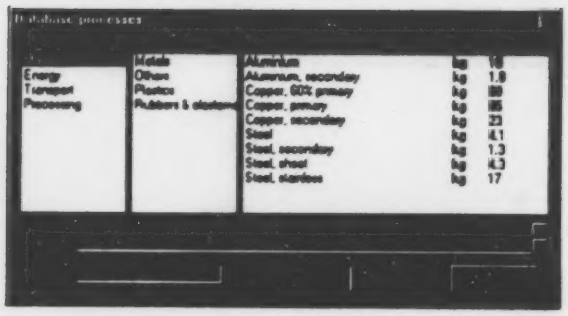
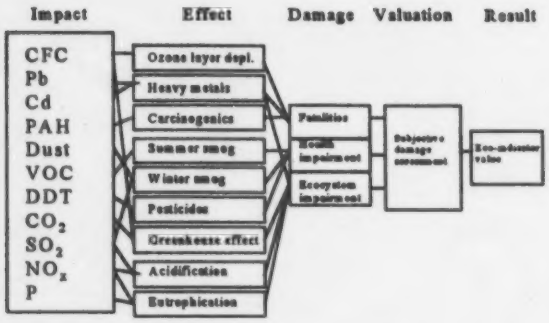


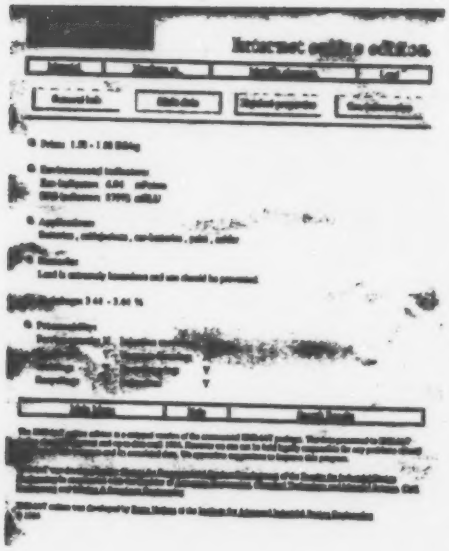


Result for the production of 1 MJ of heat from oil

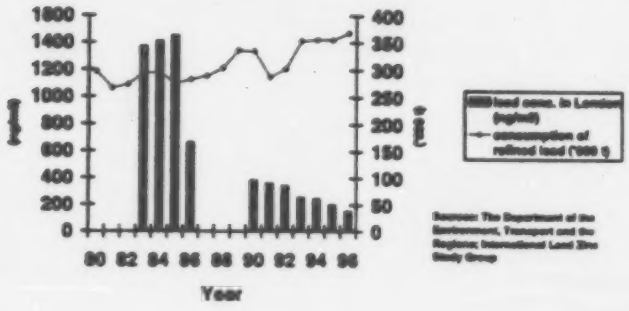
Production method	Impact	Quantity (kg)	Effect	Result partial (eco-point)	Result (eco-point)
					0.15×10^{-3}
Furnace oil	SO_2	6.59×10^{-4}	acidification	5.84×10^{-5}	
			winter smog	3.49×10^{-5}	
	NO_x	1.74×10^{-4}	acidification	1.07×10^{-5}	
			eutrophication	2.95×10^{-6}	
	.	.	.	.	
Crude oil B	.	.	.	.	
	.	.	.	.	

Calculation of the partial result

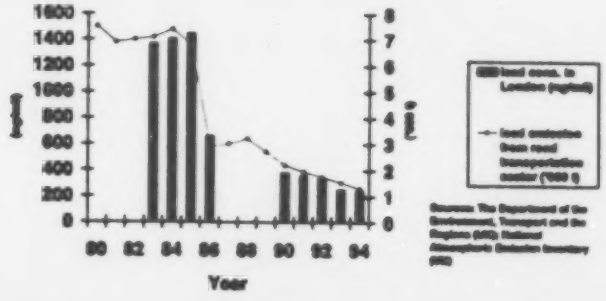
- $(Pt/kg)_{NO_x\text{-acidification}} = (1.07 \times 10^{-5}) / (1.74 \times 10^{-4}) = 0.061$
- NO_x : aspect acidification
- relative effect to SO_2 : 0.7
- reduction factor : 10
- dose /person : 113 (kg SO_2 / person)
- $(Pt/kg)_{NO_x\text{-acidification}} = ((0.7 \times 10) / 113) = 0.061$



Time series for the average annual air lead concentration in London and for the annual consumption of refined lead in the United Kingdom



Time series for the average annual air lead concentration in London and for the annual lead emissions from road transport in the United Kingdom



Design choice for 1 kg of copper, according to Eco-indicator 95

Material	Design	Eco-indicator score (Pt)
virgin	recycle	0.026
	landfill	0.090
100% recycle	recycle	0.023
	landfill	0.028

Design choice for 1 kg of copper, according to the closed loop concept

Material	Design	Eco-indicator score (Pt)
virgin	recycle	0.023
	landfill	0.090
100% recycle	recycle	0.023
	landfill	0.090

Conclusions

- relevance of the basic equation ;
- consideration for avenue of product stewardship ;
- better acknowledgement for the recycling of metals ;
- refinement of the data modeling to ensure compatibility in the boundary definitions ;
- consideration for wider environmental impact conditions outside Europe

Discussion for Session 2 and 3

Moderator: Stephen Guerin (Design Exchange, Canada)

Theme: Is it a gap between developers and users of LCA? Other stakeholders, NGO's and government: answer to this problem? How can prospective users effectively use the models?

Martin Baitz (University of Stuttgart, Germany):
The question is addressed to Nils Larsson. The compilation of the inventory data, which is the important basis, takes a lot of time. Where do you get the data ?

Nils Larsson (Natural Resources Canada):
So far, we have only the system. The national team will start the assessment process, at the earliest, the first week of December. In reference to our framework, the embodied energy and embodied emissions are not operational now. In the future, we will compare the embodied energy and emissions to the whole system emissions. The embodied emissions are put off a little.

Mark Goedkoop (PRé Consultants, the Netherlands):
In reference to Alain Dubreuil's presentation [where the Eco-indicator 95 model was analyzed], a global reduction in Europe of the SO_2 emissions will lead to an increase in the eco-indicator value for SO_2. The apparent problem of SO_2 impact that goes on the wrong way is not a weak spot but a misunderstanding by Alain of the concept.
Another concern -- in some applications that use the Eco-indicator 95 model, developers can make claims such as the use of lead should be limited due of its toxicity. This is a real concern because people are running away with it and putting it in various applications, adding things not related to the Eco-indicator 95 model, without warning. We have established some codes of practice. If you use eco-indicators in software, you should say something in regard to the background.
The third point is that winter smog is not a problem in Canada but it is in Europe. I am considering that point an an invitation to make a Canadian or North American version of the Eco-indicator model.

Patrice LeBlanc (TerraChoice, Canada):
I would like to raise some misconceptions regarding eco-labeling and the Environmental Choice Program (Canada's eco-labeling program). The ecologo program is not intended to be an eco-indicator, per say. It is used to identify environmental leadership in the product category. The examples given for the three indicators for automotive fuel are quite irrelevant since there is no such use of the indicators in the ecologo program. The only one we use for fuel has the criterion for a 10% ethanol concentration. Nor do all consumers want detailed information. However, the guidelines and criteria developed for the eco-labeling program are available to the public. On the licences for gasoline, you can

see right on the pump: 10% ethanol with the ecologo. So, there is some information you can see. Industries can provide details if the consumers demand it but TerraChoice does not have the liberty to provide any confidential information. The guideline does get revised, to maintain the leadership aspect of the program. Can you give me an example where the use of ecologo has stifled any innovation?

Marlo Raynolds (The Pembina Institute for Appropriate Development, Canada):
The 1996 version of the automotive fuel criteria that I received from TerraChoice incorporates various alternative fuels. Is that correct?

Patrice LeBlanc:
That version has not actually been approved.

Marlo Raynolds:
The question "does the use of ecolabels stifle innovation?" remains. The 10% ethanol blend is a perfect example. The criterion for eco-labels is 10% of ethanol blend. Based on greenhouse gases, the question remains on how much improvement will be made with that type of gasoline. A new process using lignocellulose to generate ethanol will get the same ecologo as the corn-based or wheat ethanol. The production of greenhouse gases is approximately half from the lignocellulose process when compared to the current ethanol production process and both will get the same ecologo. How does the ecologo recognize that difference? How does it promote the innovation? The ecologo can be improved to help the innovation.

Rick Hilton (Inco, Canada):
I would like to discuss the concept of performance or operability of a product in addition to the selection of the "greenest material" to be used in a product. Operability is equally important but, so far, not discussed in this workshop. Physical and chemical properties of a substance used in a product are very important. For example, by specifying the use of stainless steel bowls rather than plastic bowls in washing machines, manufacturers in Japan were able to increase the spin rate of the bowl and, as a consequence, to reduce the energy required to de-water the laundry. In reference to the green selection scheme presented by the Volvo representative, if only that criterion is followed, aircraft engines could be held together with plastic screws if determined to be the "greenest" material. I would not want to fly in such an airplane! The designer who may use such selection criteria should always be warned that the performance or operability of a product is still a critical component in material selection.

Agneta Wendel (Volvo, Sweden):
The environmental perspective is one of the 16 properties that we have to take into account. It is a way of describing the environmental perspective of that particular component. It is by no means that we have to go only by the results of LCA. We would have failed if we had put plastic parts in our engine. It is an educational tool and designers have to take two or three days training before they have the authority to use it.

Rick Hilton:
I think that it is important because a lot of those eco-indicators are going to architects or procurement officers who do not understand the properties of material. They can select materials based on the greenness of that material. We have to be careful with those systems and ensure there are some rules in terms of reference up-front.

Agneta Wendel:
All the staff within the company became educated in the Environmental Priority Strategies (EPS) and everybody should be aware of the advantages and disadvantages of using the system.

Jane Bare (U.S. Environmental Protection Agency, U.S.A.):
In the Saturn project, they made performance analysis separate from the environmental analysis. They actually performed the cost and performance analysis first and after they determined alternatives that were favorable, they conducted the environmental analysis.

?:
The use of eco-indicators does not mean only looking from cradle to grave of the product itself but also to look at its use. The energy use should also be considered

Nils Larsson:
We had a lot of discussion regarding to the scope of our system Some were for a full breadth system of the whole building performance including issues such as functionality (e.g., How functionally suitable is this meeting room?) That kind of basic core question was left out of the formal green assessment framework, but we have assumed there will be a preliminary assessment of code compliance, basic functionality, cost and accessibility for handicapped persons, before a green assessment is done.

Stephen Guerin:
At Nortel, do you have an engineering check and balance to prevent the use of a material that should not be used for a particular application?

Duncan Noble (Nortel, Canada):
Our approach to "design for environment" adds environmental criteria to the design process that already includes traditional concerns like cost, performance, quality, user value and esthetics. So we are adding criteria, not taking away anything. As part of our design process, we only use materials that have been qualified to rigorous performance standards for a particular application.

J. William Owens:
How do we use our values in making decisions? Will we use the values of others that are embodied, including those within all the software programs, without thinking? I think that it wrong to do so. Allow me to relate a proposal from the recent SETAC work group on LCA impact assessment: the starting process for values is outside LCA and LCA study. It starts in the top management of an organization. Once your values are clear, you ask: What are the environmental principles by which you operate, what are your environmental goals and aspirations? Then, how do you measure those and communicate them to others? In that framing context, you can then go to the LCA goal and scope phase, the actual planning of an LCA study. Then, you can say in an honest and transparent manner with management support: this is what I am going to measure with my LCA study and why. From there, you can collect the right data for your study, rather than taking them blindly from a data base. You do the right thing, at least, in a function of the organization's principles and the study context, and you can explain your actions in a more transparent way, both to your own management and to diverse external audiences.

Jane Bare:
I think that we all agree on that. We are pretty much in agreement.

Mark Goedkoop:
It is a very good proposal if you are considering large companies which have an environmental policy and can perform an LCA. Eco-indicators are a quick tool for designers. At PRé we made some kind of default goal definition for all companies. Bigger companies can change the default and use something else.

J. William Owens:
In that case, what the small companies are accepting as their own values, unconsciously swallowing whole without consideration, is a set of values from the software developer. As long as they consciously accept to swallow these values, that it is fine.

Tim Huxley (Stelco, Canada):
With respect to the Waste Minimization and Prioritization Tool (WMPT), you started with a conclusion about virtual elimination regarding some substances, and you built from that. As you take on the tool, you have already accepted the premises up-front. You weighted the program before you started in respect to where you headed. In opposition, Linda Brown looked for the impact of the environmental stressor and it tends to be a more transparent process. I find that the weighting is difficult. It is also difficult in the way tools can be used. Eco-indicators are used in design concepts but will be used for material comparison, for public policy decisions (do we like lead, copper or anything else?). The mixing up is taking place. How do you foresee clearing that situation up to get the transparency that we need?

Jane Bare:
With regard specifically to the WMPT, I did not spend enough time explaining the tool and its use. I am not endorsing this tool for any particular use. I did NOT help develop the

tool; I am not a regulator. I am not a policy maker. I am part of EPA's Office of Research and Development. They asked us: "What do you think about using this tool?" They also asked us to help develop a list of PBTs -- Persistent Bioaccumulative Toxins -- for the United States. We provided significant comments on the limitations and caveats of using this tool and the methodology for PBT selection. But again, I am not involved in the policy setting and/or regulation development.

Patrick Finlay (Environment Canada):
I can see a use for the eco-indicators. Do you have an example of a purchasing agent or an engineering team which actually made a decision based on these factors? An example was given in another forum by the University of Stuggart with the Golf automobile.

Agneta Wendel:
I cannot give a specific example. The environment is one property among others. The EPS/LCA are involved early in the project in the concept phase along with other properties. We cannot say that decisions were made only based on EPS.

Jane Bare:
In relation to the Saturn project, the performance analysis and the cost analysis did favor the alternative material and when the environmental analysis favored it as well, it was an easy decision. I do not know how significant an environmental difference would have been required to overcome an opposing result within the performance and cost analysis

Nils Larsson:
In our demonstration program, we try to do very high performance design and to consider environmental issues. In one project, engineered wood was used instead of the traditional steel and concrete structure, and this was a significant cost saving. The integration of various considerations in the design process is seen by all those involved as useful, but it does make it difficult to estimate how much of the total savings can be attributed to the energy measures alone.

Session 4: Round-table

Session 4: Round Table

Patricia Hayes from Resources Futures International (Canada) moderated the round table.

What are the key elements of a good model?

The eco-indicators' models are large, complex models. Indicators are measurable and meaningful but they do not measure the environmental impact. Impact measurements are important to put the type of indicator in context.
There is a need for clear indication of the uncertainties' propagation in results and in conclusions. The valuation (damage assessment) is impossible according to some. There are about 20 different weighting methods. There is no uniformity in the normalization.

Some key elements to be considered in a model are:

- sensitivity analysis to indicate where it is important to refine the model
- transparency
- aggregation vs disaggregation:
    - aggregation: eco-label
    - disaggregation: a lot of data

What are the uses of the models?

- help to prioritize: need quick, easy and reliable method
- internal: large corporation, design decision
- external: environmental performance
- public sector in Europe: similar to Eco-indicator 95 for grants
- progress can be made by using the concept of product stewardship. That model is being used with success by the Responsible Care Program where suppliers and clients are working together.
- the use of an Environmental Management System (ISO 14000) can lead to environmental progress.
- need of eco-indicators for infrastructure development

What are the barriers and opportunities to the use of those models?

Barriers:

- not enough data
- valuation
- paralysis by analysis
- the government should not put a brake on those initiatives
- need peer review of the different methodology

- need some type of standardization (SETAC type)
- concerns of the industry on how data will be used (confidential information vs competitor or vs other industry)

Opportunities:
- doing right
- internally: use the method more rapidly
- externally: ISO 14003 document for specification of impact assessment
- development of shared data base such as the Canadian Raw Material Data Base that compares emissions from wood, aluminum, plastic, glass and steel
- large interest from academia, industry, consultants and governments
- will be used by the industry for decision making: will have focus
- continuous improvement of models
- potentially great decision-making tool (not a panacea)

Shift from finding the right answer to useful answer. Business decision tool. From the business perspective, they will use any tool that can help make decisions. The business community can use many models and look at their difference in the output to get an idea of their sensitivity. The model should reflect the corporate culture, the issues considered and how people used it. Various models can be used at different stages of product development. As the models are refined in function of the time, it will lead to continuous improvement.

Question period

Gil Friend (Gil Friend & Associates, U.S.A.):
There is a difference between eco-indicators and environmental measures. The eco-indicators not only account for results, but point in a direction that stands for a large body of results. Eco-indicators can be a very condensed measure. If we take simply an indicator-embodied non-renewable energy use and generation of Persistent Bioaccumulative Toxins would we be 95% or 98% as accurate as an LCA tool would be?

Hal Levin (Hal Levin & Associates, U.S.A.):
Not for buildings.

Martin Baitz (University of Stuttgart, Germany):
Focusing on energy, you cannot build up the whole environment if you have industrial processes. Some processes that release toxic substances are not energy intensive. You have a need to build this up. The choice of the impact category is very important and you need the whole variety of inputs and categories to cover all products or service units.

Mark Goedkoop (PRé Consultants, the Netherlands):
You can manage your system by energy and some toxic substances. But now we have more advanced tools that can include the effects of ozone layer depletion gases, land use,

resource extraction of metals. We can use a simple model but if there are better tools, we should use the best one.

Bill McCutcheon (Natural Resources Canada):
Observation: The biggest barrier to acceptance of LCA as a valuable tool is when it is used as a non-tariff barrier. Give me 20 pages of criteria and I can rule out the best product in the world. Some governments can favor one commodity against another based on ownership of companies.
Question: We all talk in the same direction, about the purchasers' choice and their responsibility. If you use LCA (as a consumer, because we were talking as consumers making the material choice) and make some producers change, are you ethically bound to accept the decisions made by the supplier who makes criteria for acceptable uses of his products by customers? The question might be: "Will the supplier agree to sell it to you? "

It is not always a buyers' market. For example, Inco has a process to recycle nickel-cadmium batteries in the U.S. and Canada but not in Europe. Inco can say that it will not sell to anybody who supplies NiCad to Europe.

Matthew Goldman (Roy F. Weston Inc., U.S.A.):
Some of the most successful applications of eco-indicators involved discussions with suppliers and clients and their involvement. The eco-indicators identify opportunities for improvement and establish a common form of dialogue on common environmental concerns. In some cases, it has been used to establish some environmental threshold for the suppliers. It is a value judgement on the part of the customer about the supplier's operations but it is not significantly different from any business judgement such as turnaround time or other performance criteria.

Vic Shantora (Environment Canada):
Bill [McCutcheon] made good comments. They reveal the need for an honest peer review process. There is the possibility of countries taking a self-interest position. The more we broaden it, the more we put it to experts to help us analyze it, the more the biases can be negated. With respect to the NiCad, I would hope that if INCO or others see an opportunity to capture the market for another source of secondary material, they will do so rather than not to sell to that market because INCO does not like the way the Europeans are going.

Justyna Laurie-Lean (The Mining Association of Canada):
From a larger perspective, will the use of the eco-indicators get us where we want to go? We have general targets (CO_2 reduction, reduction in ozone depletion gases, reduction in acidification gases). Is there a way to check if the use of the eco-indicators' models will drive the product design, product use in a direction to achieve some of those targets?
I am not 100% sure. There is a model where an increase in the energy price will lead to a decrease in energy consumption. What percentage does the eco-indicator model make? What can we get in the real world in terms of reduced emissions, reduced impacts? It is

not an easy answer. It can be the real way to judge the models and their use. Will the model get us there?

Patricia Hayes:
Is there evidence that the model makes a difference? What will it take for the model to make the difference?

Hal Levin:
There is a variety of models. The Montreal Protocol on ozone-depleting compounds is an example of a reasonably successful model on a global scale. Ground level ozone is a different problem. Should California be prohibited from adopting more stringent standards for motor vehicle emissions when it has the most serious air pollution problem in the U.S.? Should the air quality of the Los Angeles Basin be averaged with the air quality of Wyoming to arrive at a target emission value when there is no relation to the photochemical smog in the Los Angeles Basin and emissions from vehicles in Wyoming? Environmental issues need to be treated at the appropriate scale for each problem. We have to establish goal setting, evaluation, normalization, scoping the problem, boundary definition and what is claimed as the result of the analysis in terms of its source and impact-specific areas. There is a need to be more explicit at every phase of the analysis of any model.

Patricia Hayes:
Where do you see strong application of the "eco-indicators" in the public and private sectors?

Thomas Gameson (European Commission)
The use of these models for green public purchasing is a very strong application. It represents 5 % to 15 % of OECD consumption and is going to be very important for the future of these markets. The public sector in the OECD will be involved more and more in these issues.
Other uses of the model include prioritizing and finding hot spots. Some companies have found out that they do not need eco-indicators based on complicated models when they have a good environmental management system. Other companies are utilizing weighting mechanisms for internal management purposes or to determine if a plant or business unit is performing well when compared to others (benchmarking). There is a range of internal and external applications. If these models are used for decision-making purposes, they must be linked to some kind of management system.